PRACTICAL PHYSICS FOR BEGINNERS

STEWART AND GEE

ELECTRICITY & MAGNETISM

Ph. Gen

PRACTICAL PHYSICS

Phys. S.

PRACTICAL PHYSICS

FOR

SCHOOLS AND THE JUNIOR STUDENTS OF COLLEGES

BY

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PREFACE

It has frequently been a matter of remark that while many schools are provided with fully equipped chemical laboratories, yet very few have any appliances for teaching Practical Physics. The reason is certainly not to be found in any fundamental unsuitability of Practical Physics as a training for the mind, inasmuch as the subject is universally acknowledged to be of very great importance in this respect. There are several causes which have militated against the introduction of Practical Physics, the chief, perhaps, being the want of properly trained teachers, the absence of organised methods, and the difficulty of obtaining suitable apparatus. We venture to think that, as the importance of the subject comes to be realised, there will be no lack of good teachers, each of whom will be capable of controlling a system of instruction suitable to the boys under his charge. Again, we think that instrument makers are becoming more alive to the requirements of elementary students, their strength hitherto having been mainly directed towards the manufacture of instruments suitable for commercial purposes and scientific research.

It was represented to us by several teachers that abstracts of our *Elementary Lessons in Practical Physics* might be made the basis of good school courses. We have accordingly tried the experiment with Electricity and Magnetism, so that the present volume largely consists of simple experi-

ments and measurements in Electrostatics, Magnetism, and Current Electricity, the principles of which are at the same time explained to the student. We have, however, prepared something more than an abstract. Chapter I. has been supplemented by several new lessons. Chapter II. has been largely rewritten, new instruments have been devised, and a number of new engravings have been prepared. In the Appendix will be found plans of certain typical school laboratories, a list of apparatus, tools and materials, and other information that should be of value to the teacher.

Furthermore, to make the volume complete in itself, we have given, at the commencement, a series of Introductory Measurements, with which it is essential the student of Electricity and Magnetism should be familiar.

The greater part of our course should be easily within the range of schoolboys, whilst sixth-form boys should find the more difficult portions a good introduction to advanced work.

Our thanks are due to Professor T. H. Core for looking over the proofs, and to Messrs. Henry Holden, B.Sc.; C. H. Lees, B.Sc.; and R. W. Stewart, for help in preparing the new lessons.

THE OWENS COLLEGE, MANCHESTER,
December 1887.

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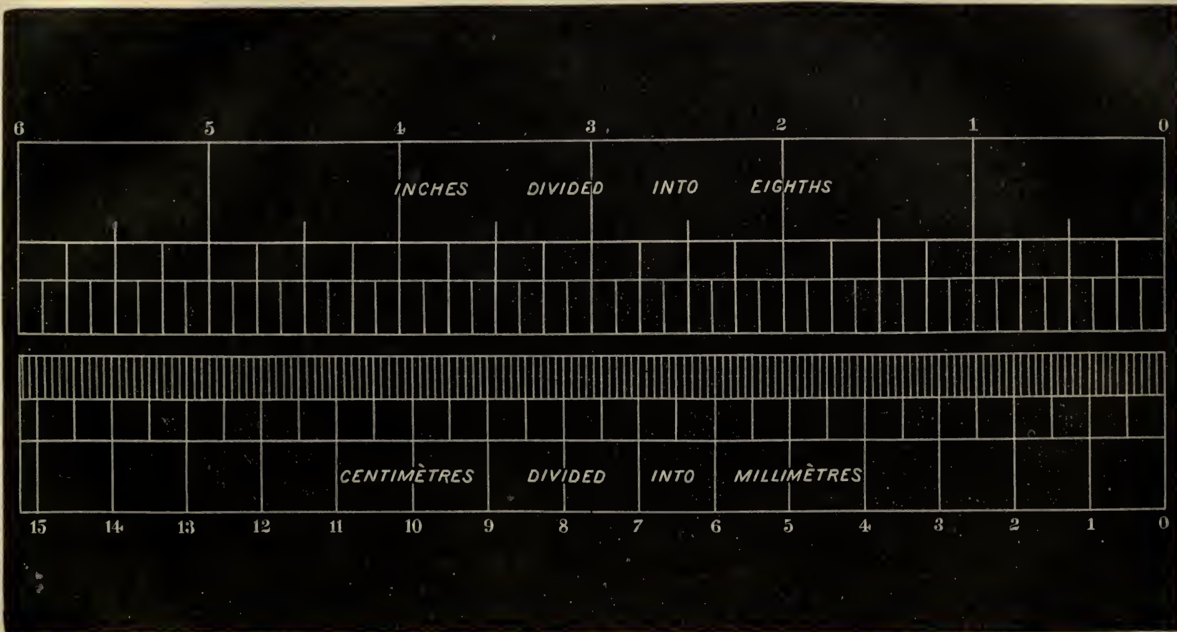
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CENTIMÈTRES DIVIDED INTO MILLIMÈTRES
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PRACTICAL PHYSICS FOR SCHOOLS.

INTRODUCTORY MEASUREMENTS.[1]

LENGTH.

(1.) **Length** is measured by comparison with a standard rule or scale.

In Great Britain the **yard** is the national standard. The yard is defined to be the distance between the centres of two gold plugs in a bronze bar deposited in the office of the Exchequer, the temperature of the bar being 62° Fahr.

When it is convenient to use smaller units of length, the **foot**, or $\frac{1}{3}$ of a yard, and the **inch**, or $\frac{1}{12}$ of a foot, are employed. The inch is most frequently divided into tenths, but sometimes into 8, 16, 32, or 64 parts.

For scientific purposes the standard is the **mètre**, which was intended to be the 10,000,000th part of the distance from the earth's equator to one of its poles measured along a meridian. Practically, however, it means the length of a certain rod of platinum at 0° centigrade. The mètre is subdivided decimally, each mètre containing 10 décimètres, each décimètre 10 centimètres, each centimètre 10 millimètres. Its higher multiples, the décamètre, hectomètre, and kilomètre, which are respectively equal 10, 100, and 1000 mètres, are seldom required for laboratory work.

Abbreviations to be used.

mètre, m.; centimètre, cm.; millimètre, mm.

Pronunciation.

In England it is getting customary to pronounce the names of the

[1] For more complete details relating to these Introductory Measurements see Stewart and Gee's *Elementary Practical Physics*, vol. i.

French measures as if the words were English. Mètre is pronounced meeter.

TABLE *a*.

RELATION OF METRICAL TO ENGLISH MEASURES OF LENGTH.

1 mètre = 39·37 inches = 1·0936 yards.
1 inch = 25·39 mm. = 2·539 cm.

Less Exact Values.

1 mètre = A yard and a tenth.
1 millimètre = $\frac{1}{25}$ inch.
1 inch = 25·4 mm. = 2·54 cm.

A diagram showing the two scales is given on the inner side of the front cover of this book.

AREA AND VOLUME.

(2.) The most useful units of area in the laboratory are the square inch and the square centimètre.

1 sq. cm. = ·155 sq. inch.

To find the areas of regular figures we use the rules of Mensuration, of which we shall need two :—

To find the area of a square or rectangle, *Multiply the length by the breadth.*

To find the area of a circle, *Multiply the square of the radius by* 3·1416 (*or for rough measurements, by* $\frac{22}{7}$).

The most convenient units of volume are the cubic inch and the cubic centimètre.

1 cub. inch = 16·386 cub. cm.

To find the volume of a right prism or cylinder, *Multiply the area of the base by the height.*

The volume of liquids is ascertained by means of graduated vessels. These are best divided into cubic centimètres. 1000 cubic centimètres is *a litre.* Flasks are made to contain *a litre, half litre,* or *quarter litre.*

Exercises.

1. How many centimètres are in a kilomètre?
2. Reduce 6·823 décamètres to millimètres.
3. Find the number of centimètres equivalent to 20 mètres added to 20 inches.
4. Measure the top of your bench and ascertain its area in square inches and square millimètres.
5. Find the number of cubic inches and cubic centimètres of wood in the top of your bench.

Lesson A.—Use of Scales.

(3.) *Exercise.*—Two small crosses are ruled upon a penny. It is required to measure the distance between the points of intersection.

Apparatus.—A pair of compasses (spring bows are the best, see Fig. *a*), also several scales, one divided into half millimètres, one into 64ths of an inch, a diagonal scale, and a glass millimètre scale.

Fig. *a*.—Spring Bows.

Method.—Apply the compasses to the penny, so that one of its points may be in the centre of one of the crosses, and the other of its points in the centre of the other, then apply it to the several scales. Convert all measurements into inches.

The construction and use of the diagonal scale may be understood from Fig. *b*. There are eleven equidistant horizontal parallel lines running through the whole scale, and dividing it into ten spaces.

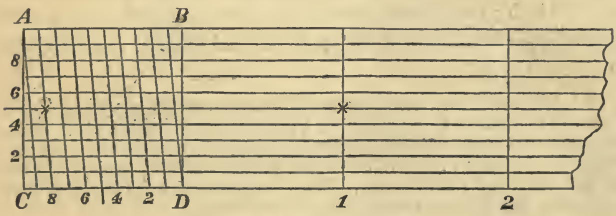


Fig. *b*.—The Diagonal Scale.

These are cut at right angles, at distances of half an inch, by vertical lines marked 1, 2, 3, etc., and by this means the whole scale is split up into a number of spaces or regions.

In the space or region at one end of the scale the lines AB and CD are divided into ten equal parts, and from the points of division diagonal lines are drawn, as shown in the figure. There will thus be two terminal triangular spaces, the sides of which are AC and BD, and nine intermediate slanting spaces. To measure a distance by means of the diagonal scale, place one point of the compass at one of the divisions, 1, 2, 3, etc., and suppose that the other point falls between two of the slanting diagonal lines, both points being in the bottom horizontal line.

Suppose, for instance, that one point is at 1, and that the other falls between 8 and 9 on the diagonal scale, then the length lies between 1·8 and 1·9. To find the length to a second place of decimals slide the compass horizontally up, keeping its right-hand point in the verti-

cal line 1 until the left-hand point meets the intersection of a diagonal with a horizontal line. Suppose, for instance, that when one point is at the star on the line 1, the other is at the star on the diagonal line 8 and horizontal line 5; then the measurement will be 1·85 or =0·925 inches, the scale being one of half inches.

The diagonal scale may be used instead of a finely-divided scale. It is ostensibly made to measure to ·0025 inch; but, as ordinarily constructed of boxwood, it cannot be depended on to this extent.

In conveying the measurements to the scales an error may be made. This may be avoided by using the glass scale and applying it directly, etched surface downwards, to the penny. Although only divided into millimètres it will be found easy, by this scale, to *estimate* with the naked eye to the tenth of a millimètre by means of an imaginary subdivision of the millimètre into ten parts. Correctness in this estimation, which is one of the first things to learn in Physical Measurements, can only be attained by practice. It will be found that, with the unpractised observer, there is a tendency to estimate the ·3 too great and the ·7 too small.

Example.—A length on a scale, divided into 64ths of an inch, was $\frac{27}{64} = \cdot 422$ inch; on a scale divided into half millimètres it was 10·75 mm. $= \frac{10 \cdot 75}{25 \cdot 4} = \cdot 423$ inch; while on a diagonal scale it was ·85 of half an inch $= \cdot 425$ inch.

(4.) With ordinary scales under favourable conditions we have seen that it is possible to estimate to $\frac{1}{10}$ millimètre or ·004 inch by the naked eye. Greater accuracy may be obtained by using a sliding scale which was invented in 1631 by Pierre Vernier.[1] This device is known by the name of its inventor. The Vernier has in practice entirely superseded the diagonal scale.

Lesson B.—The Straight Vernier.

(5.) *Exercise.*—To find the length of a rod by means of a scale provided with a Vernier.

Apparatus.—A paper scale, divided into half inches, is mounted on wood, and provided with a Vernier. The Vernier is 9 half inches in length, and is divided into 10 equal parts.

Method.—Place the rod AB (Fig. *c*) with one end at the zero of the scale, and bring the zero of the Vernier to coincide with the other end of the rod, as in the figure. It will be seen that the rod is between 2 and 3 units long. It will likewise be seen that 6 on the Vernier is in coincidence with one of the scale divisions; and the following simple proof will show that the true length of the rod is 2·6 units. Since 10 divisions on the Vernier = 9 divisions of the scale, therefore 1 division

[1] Pierre Vernier, *La Construction, l'usage et les propriétés du quadrant nouveau de Mathématiques.* Bruxelles, 1631.

of the Vernier $= \frac{9}{10}$ of a scale division, or each scale division is $\frac{1}{10}$ larger than each Vernier division.

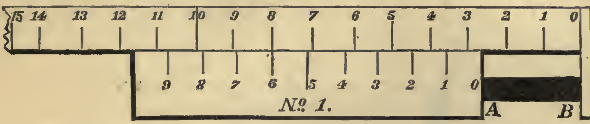


Fig. c.—The Vernier.

Therefore, since the coincidence is at 6 of the Vernier, the interval between

7 on the scale	and	5 on the	Vernier	= ·1 unit.
6 ,,	,,	4 ,,	,,	= ·2 ,,
5 ,,	,,	3 ,,	,,	= ·3 ,,
4 ,,	,,	2 ,,	,,	= ·4 ,,
3 ,,	,,	1 ,,	,,	= ·5 ,,
2 ,,	,,	0 ,,	,,	= ·6 ,,

We thus know that the rod is ·6 greater than 2, that is, its length is 2·6.

Lesson C.—Use of Callipers—The Slide Calliper.

(6.) *Exercises*—(1.) Measure the diameter and thickness of a number of discs of metal, or ordinary coins,[1] and calculate the area and volume of each in metric measure. (2.) Measure the inside and outside diameters of some metal washers, and calculate the area of the annulus. (3.) Measure the inside and outside diameter of a cylinder and its length, thence deduce the volume of liquid it would contain.

Apparatus and Method.—Callipers (Fig. *d*) are specially employed for measuring the external or internal diameters of curved bodies. The *Outside Callipers* constitute a compass with curved legs. The points must be set so that they just glide over the cylinder or other body to be measured, and they are then applied to the rule. The *Inside Callipers* are used in a similar manner to find the internal diameter of a hollow cylinder, hemisphere, etc. The tool is introduced into the cavity and the points set as before. Fig. *d* shows the two kinds combined in one instrument. In the compass (Fig. *a*) as well as in the callipers, the distance between the points is adjusted by aid of a *joint*.

Fig. d.—Callipers.

The instrument may also be made on the slide principle, and when

[1] It is useful to know that the diameter of a halfpenny is exactly one inch.

graduated and provided with a Vernier, we have an instrument far better adapted for accurate measurements than the ordinary workshop tool. Fig. *e* shows a slide calliper reading to ·1 mm. by means of the Vernier V. In using the instrument it is necessary to first ascertain

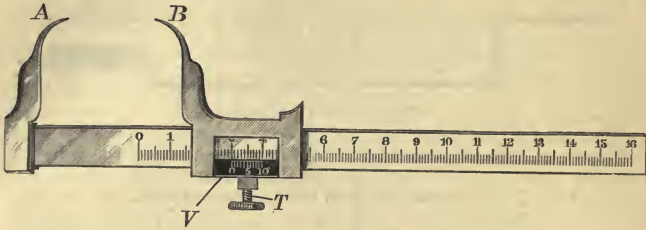


Fig. *e*.—The Slide Calliper.

that when A and B are in contact the zero of the Vernier corresponds with the zero of the scale. T is a clamp-screw.

Lesson D.—The Micrometer Wire-Gauge.

(7.) *Exercise.*—To measure the diameter of several steel and copper wires.

Apparatus.—A wire-gauge to measure to $\frac{1}{1000}$ of an inch. The wire-gauge (Fig. *f*) consists of a bent arm ABC, having at C a small cylindrical steel tooth D fixed in its place by a screw capable of adjustment. Attached to A there is a threaded tube F, into which a long screw S accurately fits. This screw is terminated by a second steel tooth at E. G is a thimble, fitting over and attached to the upper part of S, with a milled head at H, and having its lower circumference at A divided into twenty parts. At F there is a linear scale, one division of which corresponds to the distance between two threads of the screw. Thus, by means of the linear scale, we can reckon the whole turns of the screw, and by means of the scale of twenty parts we can measure twentieths of one turn.

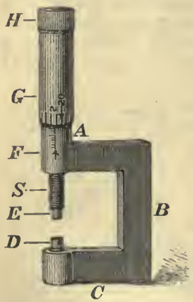


Fig. *f*.
The Micrometer Gauge.

The distance between two contiguous threads of the screw is usually $\frac{1}{50}$ of an inch, and as this is capable of being divided into twenty parts, $\frac{1}{1000}$ of an inch can thus be measured. If the screw had accurately 50 threads to the inch the divisions of the linear scale above mentioned would be divisions along a straight line parallel to the line of motion

of the screw; but the screw may not be absolutely accurate. Any such inaccuracy may, however, be remedied by reading the linear scale not along a straight, but a slightly spiral line, so contrived as to counteract the error of the screw.

Method.—First, find the pitch of the screw. This may be obtained by observing the graduations of the linear scale. The larger divisions of this generally embrace five smaller ones. If these larger divisions are found to be each $\frac{1}{10}$ of an inch, it may be taken for granted that one turn of the screw corresponds to $\frac{1}{50}$ of an inch.

The circular scale is generally divided into twenty parts, so that a circular division represents $\frac{1}{20} \times \frac{1}{50} = \frac{1}{1000}$ of an inch.

Next, screw until the teeth are in contact. If the instrument is correct, both scales should be at the zero point. If this is not the case, alter the adjusting screw which holds D in its place; or the zero error must be read and afterwards added to or deducted from the measurements.

Thirdly, to measure the diameter of a wire. Place the wire between the teeth, and advance E until the wire is held by the teeth, so that contact may be felt on both sides of the wire. In some gauges, in order that undue pressure may not be exerted, the milled head turns without advancing the tooth further when contact has once taken place. Suppose the reading to be one large and three small divisions on the linear scale, and eight divisions on the circular scale, then

		In.
One large division on linear scale	=	0·1
Three small divisions ,,	=	·06
Eight circular divisions	=	·008
Diameter of wire . .	=	0·168

(*7a.*) The diameters of wires and the thicknesses of metal plates are in commerce specified by a number known as the wire-gauge. Until August 1883 there was no legal wire-gauge, so that to know the number of a wire gave but uncertain information of its diameter. The new gauge, however, it is hoped will become of general use. On the following page (Table *a*) we give its values in English and French measure.

The approximate thickness of a wire may be readily known by using a sheet-metal gauge (Fig. *g*), which consists of a metal plate with a graduated series of notches, each notch being numbered according to some specified table of wire-gauges. It is only necessary to ascertain the number of the notch into which the wire will just fit, and then a reference to the table will give the diameter.

Fig. *g*.

TABLE a_1.

THE ENGLISH STANDARD WIRE-GAUGE.[1]

No. on New wire-gauge	Diameter.		Area of cross-section.	No. on New wire-gauge.	Diameter.		Area of cross-section.
	Inches.	Centimètre.	Sq. Centimètre.		Inches.	Centimètre.	Sq. Centimètre.
7/0	·500	1·270	1·267	23	·024	·0610	·00292
6/0	·464	1·179	1·091	24	·022	·0559	·00245
5/0	·432	1·097	·946	25	·020	·0508	·00203
4/0	·400	1·016	·811	26	·018	·0457	·00164
3/0	·372	·945	·701	27	·0164	·0417	·00136
2/0	·348	·884	·614	28	·0148	·0376	·00111
0	·324	·823	·532	29	·0136	·0345	·000937
1	·300	·762	·456	30	·0124	·0315	·000779
2	·276	·701	·386	31	·0116	·0295	·000682
3	·252	·640	·322	32	·0108	·0274	·000591
4	·232	·589	·273	33	·0100	·0254	·000507
5	·212	·538	·228	34	·0092	·0234	·000429
6	·192	·488	·187	35	·0084	·0213	·000358
7	·176	·447	·157	36	·0076	·0193	·000293
8	·160	·406	·130	37	·0068	·0173	·000234
9	·144	·366	·105	38	·0060	·0152	·000182
10	·128	·325	·0830	39	·0052	·0132	·000137
11	·116	·295	·0682	40	·0048	·0122	·000117
12	·104	·264	·0548	41	·0044	·0112	·0000982
13	·092	·234	·0429	42	·0040	·0102	·0000811
14	·080	·203	·0324	43	·0036	·00914	·0000657
15	·072	·183	·0263	44	·0032	·00813	·0000519
16	·064	·163	·0208	45	·0028	·00711	·0000397
17	·056	·142	·0159	46	·0024	·00610	·0000292
18	·048	·122	·0117	47	·0020	·00508	·0000203
19	·040	·1016	·00811	48	·0016	·00406	·0000130
20	·036	·0914	·00657	49	·0012	·00305	·00000730
21	·032	·0813	·00519	50	·0010	·00254	·00000507
22	·028	·0711	·00397				

LESSON E.—The Standard Wire-Gauge, or S.W.G.

(8.) *Exercise.*—To find the gauge number of a collection of wires by means of the sheet-metal gauge, and to compare the number given in the table with that obtained by direct measurement with the micrometer wire-gauge.

Apparatus.—Sheet-metal gauge, micrometer wire-gauge, and a number of copper or steel wires.

[1] Taken from the *Board of Trade Circular.*

ESTIMATION OF MASS.

(9.) Mass, or the quantity of matter in a substance, is estimated in terms of some standard. The legal standard for Great Britain is a piece of platinum, of which Fig. *h* shows the exact shape and size. It is taken to represent 7000 grains, or 1 lb. avoirdupois. The avoirdupois ounce is $\frac{1}{16}$ of a pound, and is equal to 437·5 grains.

The standard of mass in the metrical system is the **Kilogramme des Archives,** which is intended to have the same mass as a cubic

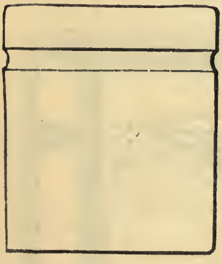


Fig. *h*.

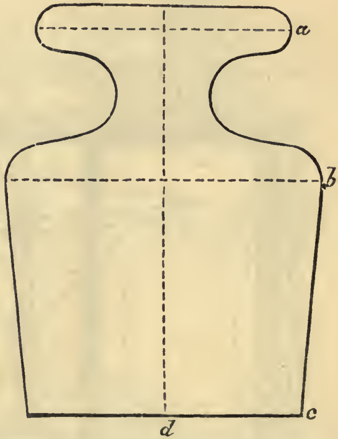


Fig. *k*.

décimètre of pure distilled water at its point of maximum density, reckoned at 4° C. The exact determinations of Kupffer have proved that the true mass of a cubic décimètre of water at 4° C. is 1·000013 kilogramme, so that, for practical purposes, the metrical standard may be taken to agree with the value which the founders of the system wished it to have. A careful copy (see Fig. *k*) has been taken of the Kilogramme des Archives, which has been accepted in this country under the Act of 1864. The metrical system will almost exclusively be employed throughout these lessons. Its relation to such masses of the British system as are commonly used is seen in the following table :—

TABLE β.

RELATION OF BRITISH TO METRICAL STANDARDS OF MASS.

1 gramme	=	15·4	grains.
1 kilogramme	=	2·2046	lbs.
1 ounce avoirdupois	=	28·35	grammes.

Less Exact Values.

$28\frac{1}{3}$ grammes = 1 avoirdupois ounce.
454 „ = 1 lb.

LESSON F.—The Balance.

(10.) A general view of a 16-inch beam balance, made by Oertling of

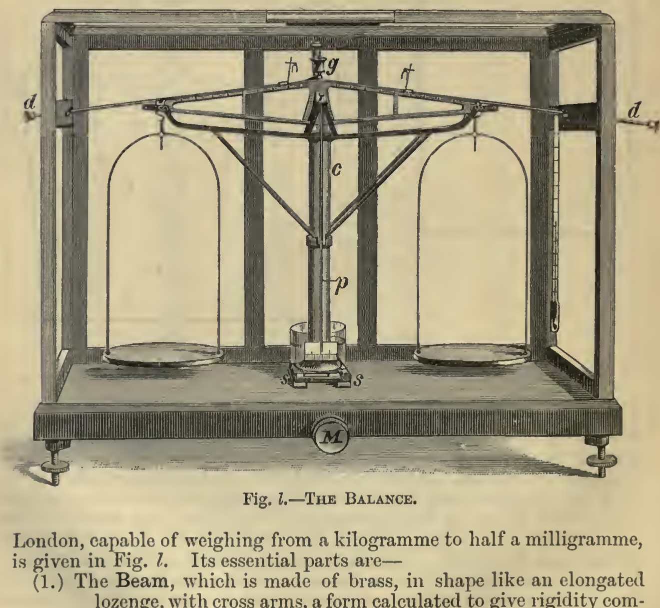


Fig. *l*.—THE BALANCE.

London, capable of weighing from a kilogramme to half a milligramme, is given in Fig. *l*. Its essential parts are—

(1.) The **Beam**, which is made of brass, in shape like an elongated lozenge, with cross arms, a form calculated to give rigidity combined with lightness. At K (Fig. *m*), the central portion, there

is a triangular brass prism with a knife-edge of agate turned downwards. At the ends of the beam there are similar knife-edges turned upwards (see k, Figs. m and n). Above the central part is fixed a bob of brass, g, called the *gravity bob*.

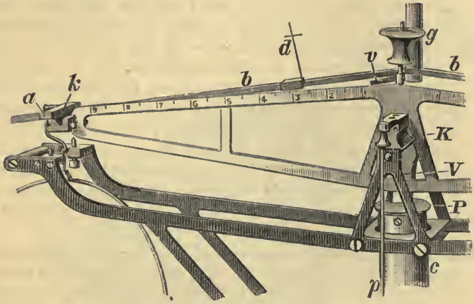


Fig. m.—BALANCE BEAM.

This may be raised or lowered by a slow screw motion. Below the gravity bob is a small vane, v, which, by turning it slightly towards right or left, may be made to correct small deviations from equilibrium.

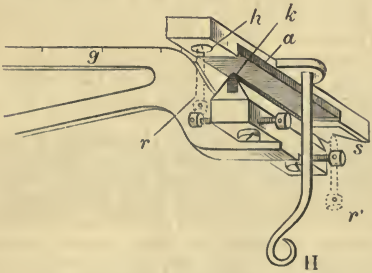


Fig. n.—END OF BALANCE BEAM.

(2.) The **Pointer**, p, which is 321 mm. long, and is attached to the centre of the beam. It moves over a graduated *scale*, made of ivory, having twenty divisions, the spaces indicated by these divisions being 1·28 mm.

(3.) The **Pillar** P (Fig. *m*), which supports the beam, and is a hollow brass cylinder. At its top is an agate plane, on which the central knife-edge may rest.

(4.) The **Pan-Supports** (Figs. *m* and *n*), which consist each of a bent arm attached to a brass bar, bearing on its lower surface an agate plane, *a*, which rests on the terminal knife-edge *k*. Each **Pan** is attached by a hook, H, to the pan-supports.

(5.) The **Knife-edges** and **Planes.**—By the use of these the balance-maker endeavours to reduce friction to a minimum. This involves the necessity of preserving the sharpness of the edges and the smoothness of the planes, and this in its turn involves the condition that the edges and planes shall only be brought into contact when the balance is in use. Accordingly in all delicate balances there is a framework which brings these edges and planes into their required positions when the balance is about to be used. The constancy of this position is secured in a manner which will now be described.

(6.) The **Arrestment**, denoted by the shaded framework. It is attached to a central tube, *c*, which forms an outer covering surrounding the greater part of the pillar—the pillar itself being fixed. By means of the large milled head, M, acting outside the balance-case by an eccentric movement, the arrestment may be raised or lowered. When the arrestment is at its highest position the central knife-edge is just lifted off the agate planes, and the terminal planes are also raised from the terminal knife-edges. Each pan-support has a hole, *h*, and slot, *s* (Fig. *n*), into which, in the raised position of the arrestment, two screws, *r* and *r′*, with conical points attached to the end of the arrestment (Fig. *n*), fit, just separating the planes from the knife-edges. At the same time two V-shaped portions of the arrestment lift the central knife-edge from its plane V (Fig. *m*). As much depends on the perfect working of the arrestment, the mechanician endeavours to make the movement as smooth as possible.

(7.) Two arms, *d*, *d*, movable from the outside, which can slide along two bars, *b*, *b* (Figs. *l* and *m*), fixed above the balance beam, and thus enable a small weight of bent wire, called a **Rider**, to be placed on any of the graduated positions on the balance arms. The rider generally weighs one centigramme, and there are nineteen graduated positions on the balance beam at regular distances from the fulcrum, so that by this means differences in weight denoting $\frac{1}{20}$ of a centigramme or half a milligramme may be easily estimated.

The balance has a case with glass doors, so that while there is convenience of access there is at the same time freedom from currents of air. The instrument is supported on four levelling screws, and is furnished with two spirit-levels, *ss* (Fig. *l*), at right angles to each other.

(**11.**) **Weights.**—The weights used are arranged in a box (Fig. *o*) in the following order :—

Brass weights.			Platinum weights.	Platinum or aluminium weights.
1000 grms.	50 grms.	5 grms.	0·5 grm.	0·05 grm.
500	20	2	0·2	0·02
200	10	2	0·2	0·01
100	10	1	0·1	0·01
100				

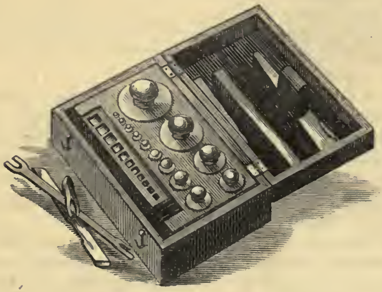


Fig. *o*.—Box of Weights.

The weights ·005, ·002, ·001, being very small, are seldom used. A wire of aluminium or gilt brass (Fig. *p*), called a centigramme rider, which may be placed at different points along the beam in the manner just described, is much more convenient.

Fig. *p*.
Centigramme Rider.

The smaller weights are protected when not in use by a slip of glass placed over the compartments that contain them. The larger weights should always be handled by means of the forked piece of ivory, and the smaller weights by pincers (Fig. *o*). They should be covered with some metal which is not subject to oxidation. They are often platinised. If they are gilt, care must be taken that they do not come in contact with mercury. A similar remark applies to the scale-pans.

Lesson G.—Method of Using the Balance.

(**12.**) *Apparatus.*—The balance, which we shall suppose to have been put into good adjustment, a box of weights, a rider, a camel-hair brush, and an object to be weighed.[1]

[1] It is a useful exercise to weigh a number of coins.

Method.—On the left-hand pan, which may be named the object-pan, place the body to be weighed, and in the middle of the right-hand or weight-pan such weights as are estimated sufficient to counterbalance the body. Suppose that 50 + 20 grms. are used, and that on partially lowering the arrestment the pointer is seen to move towards the object, indicating that these weights are too great. Suppose next that on substituting 10 for 20 grms. the weight is found to be too little. The subsequent steps of the process are as follows:—

50 + 10 + 5, too great.
50 + 10 + 2, too little.
50 + 10 + 2 + 2, too little.
50 + 10 + 2 + 2 + ·5, too little.
50 + 10 + 2 + 2 + ·5 + ·2, too little.
50 + 10 + 2 + 2 + ·5 + ·2 + ·1, still too little, but not far from the truth. ·005 is next added, which proves too great; and finally, on substituting ·0025 for it, the pointer swings equally on both sides of the central line of the scale. The weight is thus found to be 64·8025 grms.

As the student becomes familiar with the balance he will learn to weigh quickly and know from the swinging of the balance how much to add in order to obtain equilibrium.

During the process of weighing it will be necessary to observe several precautions. For the sake of convenience let us arrange under one head the general course of procedure in using the balance, as well as the special precautions necessary.

Precautions in Weighing.

1. See that the rider is in its place—on its supporting arm, and not likely to touch the beam during the oscillations of the balance.
2. Brush the pans with a flat camel-hair brush.
3. Lower the arrestment to see whether the balance swings equally on both sides of the scale. If not, adjust the vane carefully until it does so.[1]
4. Do not stop the swinging of the balance with a jerk. It is best to stop it when the pointer is at its central position.
5. Stop the swinging of the balance when weights are to be added or taken away.
6. The position of the observer should be central, so that there may be no parallax in observing the position of the pointer.
7. If the balance is nearly in equilibrium there may be a difficulty in getting up a vibration; in this case gently waft the air over one of the pans. Or the arrestment may be raised and lowered again; one or two attempts will set up the required swinging.

[1] The frequent adjustment of the vane is objectionable, tending to produce injury of the balance; so that when a balance is in much use it is better to correct for slight want of balance by adding weight to one arm, or by making an allowance in scale divisions for the deviation of the pointer from the centre.

8. Place the large weights in the centre of the pan and the smaller weights in the order of their denomination.
9. Final weighings must be made with the balance-case closed, and care must be taken that the pans do not swing.
10. Do not weigh a body when hot; the heat causes air-currents, which affect the weighing.
11. All substances liable to injure the pans must be weighed in appropriate vessels.
12. Hygroscopic bodies must be weighed in closed vessels, as also volatile liquids.
13. Remove the weights from the pans, the rider from the beam, and close the balance when the weighing is finished.

ESTIMATION OF DENSITY.

(13.) For our purpose we can best define the density of a substance to be the weight in grammes of a cubic centimètre of the substance. Hence

Whole weight in grammes = Volume in cubic centimètres multiplied by the density.

To ascertain the density of a solid, such as a piece of copper wire, it must be weighed in air and then in water. The loss of weight in water divided by its weight in air gives the density.

ESTIMATION OF TIME.

(14.) The unit of time is the second. In place of a watch we may substitute a leaden bullet tied to a silken string, so as to form a pendulum. By adjusting the length of the string it may be made to beat seconds. In determining the time of any event two students, A and B, must work together. A, at the beginning of the event, makes a sharp tap on the table; B then commences to count the swings of the pendulum until A makes a second tap. Use may also be made of a stop-watch.

ANGULAR MEASUREMENT.

(15.) *Units of Angular Measurement.*—The ordinary unit is the **degree**, which is divided into 60 *minutes*, each minute being again divided into 60 *seconds*. The degree is the angle formed by two radii of a circle which enclose $\frac{1}{360}$ part of the whole circumference. Degrees, minutes, and seconds are written thus, $83° \; 15' \; 32''$.

(16.) *The Dividing of Circles.*—Most instruments for measuring angles are provided with a graduated circle. To graduate a circle it is generally first of all divided into six equal parts of 60° each. Each

of these is then twice bisected, giving intervals of 15°, which are ultimately divided by a method of trial and error into degrees. As far as laboratory practice is concerned, we shall assume that it is always possible to make use of a circle already graduated, the question being to copy its divisions by the method given in the following lesson.

Lesson H.—Copying of Circular Divisions.

(17.) *Exercise.*—To divide into degrees a circle of cardboard.

Apparatus.—The apparatus to be used (Fig. *q*) consists of a brass circle divided into degrees, and having a radial arm capable of turning

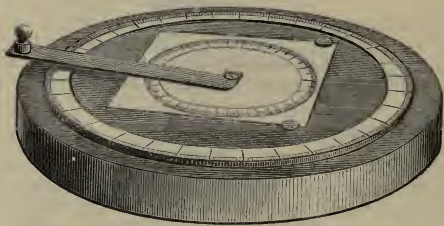


Fig. *q*.—Graduation of Circle.

about the centre of the circle. One edge of this arm is bevelled, and this edge moves exactly as a radius of the circle. Cardboard, drawing-pen, Indian ink, etc., are likewise necessary.

Method.—Remove the radial arm, and fix the stout pin about which it revolves through the centre of the cardboard circle. Replace the arm, which now has the circle beneath it, and by means of drawing-pins prevent the circle from moving. Now bring the radial arm close to the zero of the brass scale, leaving just room for the drawing-pen; then, whilst the arm is held firmly, rule a division on the cardboard. In this way the divisions of the outer brass circle are transferred, the 5th, 10th, etc., divisions being made somewhat longer than the others. The success of the operation depends upon keeping the relative position of the drawing-pen and the ruler the same at each ruling.

(18.) Very small angular movements are measured by means of a mirror and scale in the manner to be afterwards described.

CHAPTER I.

ELECTROSTATICS—ELEMENTARY PHENOMENA AND LAWS.

LESSON I.—Electrification by Friction and Conduction.

1. *Apparatus.*—(1.) Two pieces of glass tubing about 350 mm. long by 15 mm. in diameter. Each must be closed at one end by the blowpipe. The tubes must be thoroughly clean and dry. The open end should be closed by a cork to keep out dust. (2.) Several ebonite penholders. (3.) A stirrup of copper wire covered with gutta-percha, suspended by two narrow silk ribbons. Fig. 1 shows the method of making the stirrup. (4.) A pad of good silk about 150 mm. square. (5.) Electrical amalgam mixed with a little tallow. (6.) A piece of cat-skin or other fur. (7.) Two small gold-leaf electroscopes. Fig. 2 shows a convenient form of these. Here A is a Florence flask of four-ounce capacity, provided with an india-rubber cork, through which passes a short ebonite rod, *e*. The ebonite rod is perforated so as to admit the passage through it of a brass rod having a brass disc soldered at one end, while

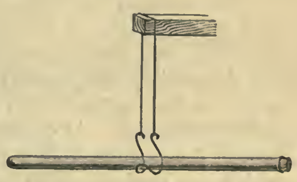


Fig. 1.

the other end is filed so as to make a knife-edge. Two gold leaves are attached to this end of the brass rod.

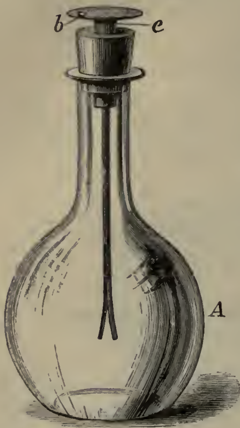


Fig. 2.
GOLD-LEAF ELECTROSCOPE.

A hole should be drilled through the brass disc at *b*, to serve for the attachment of wires. The flask must be thoroughly clean and dry. It should be well washed, the final washing being with distilled water, and then dried before the fire. The cork, with its fittings, should be inserted when the instrument is still warm. (8.) A tin can about 10 cm. long by 7 cm. wide. (9.) A block of paraffin wax. (10.) Several mètres of No. 32 B. W. G. copper wire. (11.) Several mètres of silk thread. (12.) A piece of glass tubing mounted for study of conduction.

NOTES.

Manipulation of Gold Leaf.—To supply the electroscope with gold leaves is a comparatively easy process when we are provided with the following materials as used by the gilder :—(1.) A *cushion*, this consists of a board 8 inches by 5 inches, which is first covered with baize and then with buff leather, tightly stretched. At one end is a raised edge of parchment to protect the cushion from accidental winds. (2.) A *gilder's knife*, which is a kind of palette knife with a long flexible blade, having an edge not sufficiently sharp to cut the leather of the cushion. (3.) A *tip* or large flat brush of squirrel's hair for taking up and placing the gold leaf. (4.) A powder of *burnt talc*, which is dusted upon the cushion to prevent the gold leaf from sticking to it. The leaf is transferred by means of the knife to the cushion, and then cut by pressure of the knife. The cut leaf may then be lifted by the tip, very slightly greased.

Electrical Amalgam.—This consists of an alloy of equal parts of tin and zinc which has been amalgamated with its own weight of hot mercury. Instead of this amalgam mosaic gold is often substituted. Mosaic gold is a bisulphide of tin.

Ebonite and Vulcanite.—These materials consist of a mixture of india-rubber and sulphur that has been heated under pressure. The only difference between ebonite and vulcanite is in the colouring materials used. It is necessary to protect ebonite from the action of the light, which causes the sulphur to become superficially oxidised, when, for electrical purposes, the substance becomes useless.

Paraffin Wax.—This is a white solid hydrocarbon, having a melting point at 54° C. When heated above this temperature its insulating properties are greatly diminished.

The following experiments must either be conducted in

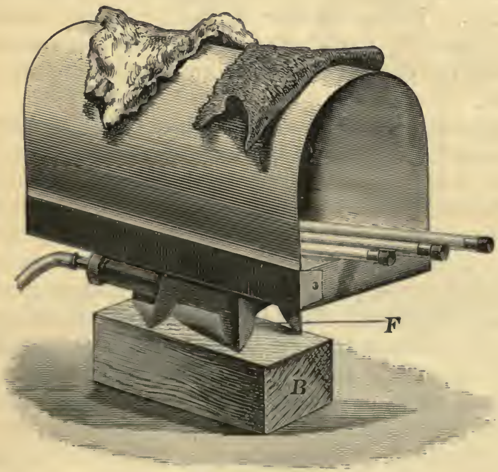


Fig. 2*a*.—Drying Oven.

a room where there is a fire, or an air bath of tin similar to that shown in Fig. 2*a* should be used, on the top of

which may be placed the rubbers of silk and fur, and inside the electroscopes and glass rods. The air bath is heated by a Fletcher's burner (F), supported on a brick (B).

Experiment I.—Electrification by Friction.—Warm both of the glass tubes, and rub one with dry warm silk on which amalgam has been spread. In absence of amalgam dry warm silk alone will answer, but not so well. The tube so rubbed must be placed so that it is supported at the middle by the stirrup. Next, take the other glass tube and rub it in the same way. On approaching the rubbed portion of the second tube to the rubbed portion of the first the latter will be repelled. All this must be done quickly, otherwise the charge may be lost. Next, rub or excite an ebonite penholder by means of warm dry fur or warm dry flannel, and replace the glass tube on the stirrup by this penholder. Excite another penholder in the same way. On approaching the excited portion of the second penholder to the excited portion of the first the latter will be repelled.

It thus appears that excited glass repels excited glass, while excited ebonite repels excited ebonite. In a precisely similar manner it may be shown that excited glass attracts excited ebonite, and excited ebonite excited glass. We thus see that the state produced in the ebonite by excitation is different from that produced in the glass. Excited glass is said to be *positively* and excited ebonite *negatively* electrified. Here the words positive and negative are merely convenient expressions, and do not imply that there is anything essentially positive in the physical state of excited glass, or essentially negative in that of excited ebonite.

Experiment II.—Electrification by Conduction.—Place the tin can on the block of paraffin, then connect the tin can with the plate of the electroscope by means of a copper wire about two mètres in length (see Fig. 3, where the electroscope is shown supported on a wooden stand). The

wire must not touch anything as it passes from the one vessel to the other. Excite an ebonite penholder and rub it upon the tin can. The two gold leaves of the distant electroscope will immediately repel each other and fly apart.

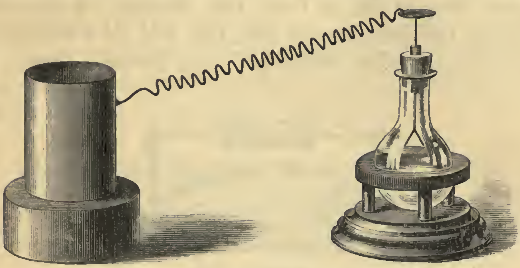


Fig. 3.—Electrification by Conduction.

Here the electroscope becomes electrified by *conduction*, the copper wire being a conductor of electricity. Next, substitute a silk thread for the copper wire, and it will be found that the electroscope will now remain unaffected, the silk being an *insulator* or *non-conductor*. Wet the silk with water and repeat the experiment. The wetted silk will now be found to be a conductor. In using the electroscope care must be taken that it does not receive too great a charge, for in this case the leaves might be torn.

If we examine a sufficiently large number of bodies we shall find that there is no essential difference between conductors and insulators, the difference being rather in the *degree* of conducting power which the various substances possess; for it will be found that by electrifying the tin can sufficiently strongly after a little time, even with a good insulator connecting the can and the electroscope, the leaves of the latter will begin slowly to diverge.

Experiment III.—Study of the Conducting Power of Glass.—Glass is so much used for the construction of electrical apparatus that it will be well for us to learn the conditions

under which it is an insulator. Take a piece of glass rod about 80 mm. long and about 5 mm. diameter. Mount it as shown in Fig. 3*a*, where *e* and *e′* are ebonite rods supported by a wooden base, *gg′* is the glass tube supported by copper wires *w* and *w′* from the ebonite. Connect the end *w* with an electroscope, and the end *w′* with the gas or water pipe. Now warm *gg′* by a Bunsen burner, and

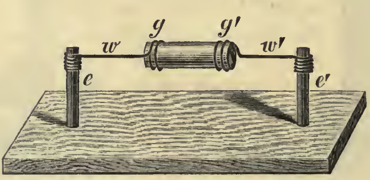


Fig. 3*a*.

it will be found that when the electroscope is electrified it either remains charged or loses its charge slowly. Next make *gg′* very hot; the glass now loses its insulating power. Allow the glass to cool slowly, and observe when it again becomes an insulator. The glass having reached an insulating condition, breathe upon it, so that it becomes covered with a layer of moisture, and the glass will no longer be insulating.

Note.—A better form of apparatus than the one figured has two brass forks in place of the wires *w* and *w′*, upon which different materials may be readily placed and tested.

The following table gives a list of substances in their approximate order of conductivity :—

Table A.

Order of Conductors.

Good Conductors . .	Metals, carbon, acids, saline solutions, water.
Semi-Conductors . .	The body, cotton, dry wood, paper.
Non-Conductors (or Insulators) . .	Oils, porcelain, wool, silk, sealing-wax, sulphur, resin, gutta-percha, india-rubber, shellac, paraffin, ebonite, glass, dry air.

Experiment IV.—All Substances of a Different Nature may be Electrified by being rubbed together.—In order to electrify a metallic substance or other conductor it must be furnished with an insulating support. Place, for instance, the tin can on the block of paraffin, and connect the former with the electroscope by means of a copper wire. Beat the tin can with warm dry fur. The leaves of the electroscope will diverge, showing that the tin can has been excited.

Lesson II.—Electrification by Induction.

2. *Apparatus.*—That of the previous lesson with the addition of the following:—Two brass knobs (ordinary

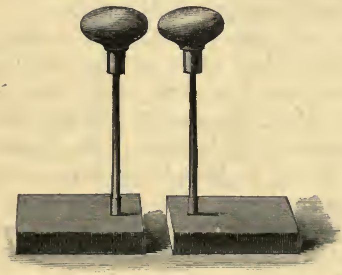


Fig. 4.—Induction Apparatus.

door handles will do very well) mounted on ebonite penholders, supported by wooden stands (see Fig. 4).

Experiment I.—Use of Electroscope.—When an electrified body is brought near the gold-leaf electroscope the leaves separate. This shows that electrification may be produced by the influence of an electrified body acting through the air. This is called *electrification by induction.* Let us proceed to study this phenomenon as it appears in the electroscope, learning at the same time the correct mode of using that instrument for testing the nature of an electric charge.

(1.) Let us first of all give the electroscope a positive charge by touching the brass plate with a stick of excited glass, which we then withdraw.

Note.—Sometimes when the brass plate of the electroscope has been rubbed or even touched with a not too highly positively charged glass rod the leaves diverge with *negative electricity*. This is caused by the *friction* of the glass and brass causing the latter to take a negative charge.

certain divergence of the gold leaves will be caused by this charge. Now, if we bring from above towards the plate of the electroscope either this charged stick of glass or another similarly excited, it will be noticed that the leaves diverge more and more widely as the positively charged glass continues to approach the plate.

(2.) If we next cause a stick of excited ebonite to approach the plate of the positively charged electroscope, we shall find that the negative charge which the ebonite has will cause the leaves to collapse. If, however, this negative charge be very strong, on bringing it still nearer, the leaves will again open out. When such a charge is quickly brought near the electroscope it is possible that the first collapse of the leaves may escape the notice of the observer.

(3.) If a conducting body, such as the hand, be approached towards the plate of the charged electroscope, the gold leaves will tend to collapse.

We see from this experiment that the slow approach to the plate of the charged electroscope of a *similarly* charged body will cause the leaves to open out, while the slow approach of a body charged with the *opposite* electricity will cause the leaves to fall together, and, if it be strong enough, as the approach is continued, afterwards to open out.

We see also that the approach of a neutral conductor

whose parts are at varying distances from the plate will tend to make the gold leaves collapse.

Experiment II.—Charging by Induction.

(1.) Having discharged the electroscope, excite a stick of ebonite and bring it near to the plate; the leaves will separate. Whilst the ebonite is kept in this position (near the plate) touch the plate for a moment, and then withdraw the finger; the leaves will now fall together. Remove the ebonite, and the leaves will again open. If we test the character of the charge it will be found to be positive, or opposite to that of the ebonite.

(2.) Had we employed a stick of glass instead of one of ebonite, the charge would have been negative. This method of charging an electroscope is called *charging by induction*, and is usually better than the other method, or that by conduction, for the reason given in the above note.

Experiment III.—Study of Induction.—Let us now proceed to inquire further into the nature of induction.

(1.) Take the two brass knobs mounted on ebonite penholders, and place the edges of the knobs in contact with each other. Then bring an electrified rod, for instance, an ebonite rod charged with negative electricity, near one of the knobs, but not touching it. Whilst the ebonite rod is in this position, separate the knobs from one another and test their charges. They will be found to be charged with opposite kinds of electricity, the one that was nearest the electrified ebonite rod being positively charged.

(2.) Repeat the experiment, but, when the electrified ebonite rod is near, instead of separating the knobs, touch either of them momentarily with the finger; both knobs will now be found to have a positive charge.

(3.) Make the experiment as in (2), but instead of touching the knobs with the finger touch them with the plate of the electroscope; the electroscope will be found to have received a negative charge.

We learn from these various experiments that when electrification by induction takes place, both kinds of electricity are produced, or rather separated from each other, in the neutral conductor, that of the same name as the charge of the inducing body having a tendency to escape. It is therefore said to be *unbound* or free, whilst that of the opposite name is said to be *bound* as long as the inducing charge is present.

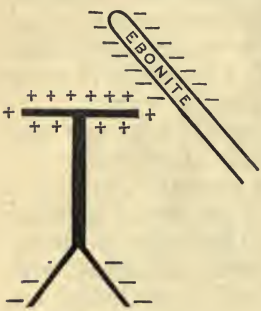


Fig. 4*a*.

Note.—To assist the student in understanding the following explanations he should make drawings in his note-book representing the successive steps of the experiments. For positive use the sign + and for negative the sign – ; or use blue and red pencils. Fig. 4*a* shows the kind of sketches that should be made.

Explanation of Experiments.—The student should now be able to understand the induction experiments with the electroscope. For instance, in Experiment I., we see why the slow approach to the plate of a charged electroscope of a similarly charged body should cause the leaves to open out, inasmuch as the approaching body may be imagined to decompose the neutral electricity of the electroscope, attracting or binding that of an opposite name to itself, and thrusting that of the same name as far away as possible—that is to say, to the leaves which consequently diverge.

For similar reasons the slow approach of a body charged with the opposite electricity will cause the leaves to fall

together, and to open out afterwards with an opposite charge as the approach is continued.

When a neutral body, such as the hand, is placed near the plate of a charged electroscope, the leaves will tend to collapse, because the electricity of the instrument will act upon the hand, decomposing (as it were) its neutral electricity, pulling that of the opposite name as near to it as possible, and thrusting that of the same name through the body to the earth. In this manner part of the charge will become *bound*, and, being withdrawn from the gold leaves, these will tend to collapse.

Again, it is manifest that when the electroscope is charged by induction, the office of the finger when it touches the plate is to take away the free electricity, or that of the same name as the charge of the inducing body. What is then left is the charge of this body, and a nearly equal amount of electricity of the opposite name in the plate of the electroscope. Both these are practically bound, and therefore do not influence the gold leaves; withdraw, however, the inducing body, and the electricity of the electroscope is now free, and acts therefore upon the leaves.

Lesson III.—The Electrophorus of Volta.

3. *Apparatus.*—(1.) A simple electrophorus (Fig. 5). A convenient form consists of an ebonite disc—*the plate*—about 60 mm. in diameter, having a metal disc, termed *the sole*, of the same size screwed to its under surface. The upper surface of the ebonite is well polished. A separate brass disc with smooth edges, somewhat smaller than the plate, is provided with a rod of ebonite as a handle, and forms *the lid* of the instrument. An electrophorus constructed in this manner is a very satisfactory instrument. A simpler variety may be made by melting ordinary sealing-wax in the lid of a round tin canister, so as to form a

smooth plate. A disc of tin, with a handle of sealing-wax, will serve as a lid. (2.) An electroscope. (3.) Fur or flannel.

Fig. 5.—ELECTROPHORUS.

Use of the Instrument.—The plate must first be excited. A few whisks with the fur of a cat will serve to electrify the polished ebonite or sealing-wax strongly. If this cannot be procured, any other kind of fur or a piece of hot flannel will do instead. Next place the lid upon the plate, and touch the metal of the lid momentarily with the finger. On raising the lid it will be found to be charged and capable of giving a spark. As often as this process is repeated the lid becomes charged, provided that the plate is freshly excited occasionally. The electrophorus thus forms a simple electrical machine. The labour of touching the disc may be avoided if a metal pin be passed through a hole in the plate, so that when the lid is in position the sole may be in connection with the lid.

Theory of the Instrument.—This may be studied by performing the following experiments :—(1.) Find the nature of the charge of the ebonite ; this will be found to consist of negative electricity. (2.) Find the nature of the charge of the lid after it has first been touched and then removed from the electrophorus ; this will be found to consist of positive electricity. (3.) Place a charged electrophorus, with its lid (untouched), upon the plate of the electroscope ; on touching the lid the gold leaves will fly apart, and will be found to be charged with positive electricity. (4.) Now, retaining the arrangement of (3), withdraw the lid from the electrophorus, when the gold leaves of the electroscope will immediately collapse.

The electrophorus thus acts by means of induction. The ebonite, when struck with the fur or flannel, is negatively electrified, and this negative electricity decomposes the neutral electricity of the sole, pulling the positive to itself and thrusting the negative into the earth. The action of the positive of the sole upon the negative of the ebonite serves to bind the latter into the substance of the ebonite. When the lid is put on, the electricity of the ebonite is not communicated by contact to the lid, the ebonite being a non-conductor, and only touching the lid in a few points. On the other hand, the lid is acted on inductively by the negative electricity of the plate, and when it is touched with the finger the free negative of the lid is thrust through the body of the operator into the earth, and, at the same time, this releases the bound positive electricity of the sole. The lid, if carried away, will thus be found to be positively electrified.

When the electrophorus is placed upon an electroscope, and in that position the lid is touched, the positive electricity of the sole, being released, is permitted to go to the gold leaves, which, in consequence, diverge. When, however, the lid is carried away, this positive is recalled into the sole, and the gold leaves collapse.

Lesson IV.—Faraday's Ice Pail Experiments.

4. *Apparatus.*—(1.) Two tin cans, one 10 cm. deep by 7 cm. wide, the other 7 cm. deep by 5 cm. wide. The larger can has a layer of paraffin wax covering the bottom; the smaller is furnished with an ebonite penholder as a handle (Fig. 6). (2.) A block of paraffin to serve as an insulating support. (3.) A small electrophorus. (4.) Two electroscopes. (5.) Connecting wires. (6.) It may be convenient to use an electrophorus lid smaller than that mentioned in the previous lesson, such, for in-

stance, as a halfpenny attached to an ebonite penholder (Fig. 7).

Note.—The student should make sketches in his note-book of the following experiments.

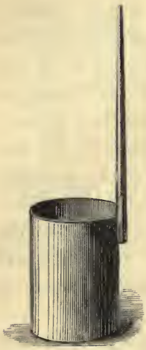


Fig. 6.

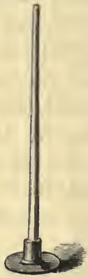


Fig. 7.

Experiment I.—Place the larger tin can on the block of paraffin, and connect the tin with an electroscope. Charge the lid of the electrophorus, and lower it into the tin can, without allowing it to touch the latter. The electroscope leaves will diverge as the lid is lowered, but when it is a little way inside the can this divergence will reach a maximum, and then remain unaltered. Now make the lid to touch the metal near the bottom of the can; no alteration will be produced by this in the amount of divergence of the electroscope leaves. The charge of the electroscope will be found to be of the same kind as was that of the electrophorus lid. Remove the lid, and test it by a second electroscope; *it will be found to be perfectly discharged.*

Experiment II.—Repeat the previous experiment, but when the lid is near the bottom of the can (not having been in contact with the metal), touch the outside of the can with the finger, so as to withdraw the external charge. The leaves of the electroscope will now collapse, but if the electrophorus lid be removed without allowing it to touch the can, the leaves will again separate to as great an extent as before. Test the charge of the electroscope, and it will be found to be of the kind opposite to that of the electrophorus lid.

Experiment III.—Place the smaller tin within the larger,

so as to make it rest upon the layer of paraffin at the bottom of the latter. Introduce within the smaller tin the positively electrified electrophorus lid. This will give rise to a condition of electrification in which the inner sides of the two tins will be negatively and the outer sides positively charged.

Now make contact between the two cans by the aid of the insulating handle of the smaller. The inner surface of the inner can will now be negatively and the outer surface of the outer can positively electrified. Next let the lid be removed, but not discharged, the inner vessel removed and discharged, and then both replaced. The outer vessel may now be made to have a double charge by repeating the above process, and a small initial electrification may thus be multiplied as many times as we please.

Note.—The student should grasp the following explanation with the aid of the sketches he has made.

Explanation of these Experiments.—When the charged electrophorus lid has been lowered sufficiently far into the can (as in Experiment I.), it acts inductively upon the can, attracting to the inside a quantity of electricity equal in amount but opposite in character to that of the lid, and repelling to the outside a quantity equal in amount but similar in character to that of the lid. When the lid touches the inside of the can its electricity combines with that equal and opposite charge which has been induced on the inside, leaving the outside electrification altogether unaffected. The lid will now be found to have no charge, because (see Lesson VI.) it has come from being in contact with the interior of a conductor, the charge of which clings to the outside.

In Experiment II. the touching of the outside of the can carries off to the earth electricity equal in amount and similar in character to that of the lid, thus causing the leaves of the electroscope to collapse. When, however,

the charged lid is removed from the inside, the electricity of the inside of an opposite character to that of the lid which was formerly bound by the lid, is now free to influence the gold leaves.

In Experiment III., after contact has been made between the two cans, the outer one is positively and the inner one negatively charged. If the inner one be now removed, discharged, and then replaced, we shall of course have positive in the outer and nothing in the inner. But if now the charged lid be reintroduced into the inner can, and contact made as before between the two cans, there is no reason why a second positive charge should not be given to the outer can.

Indeed for this purpose there is no necessity for the two cans, for if the lid, after being discharged, as in Experiment I., be recharged and introduced into the can, after contact with the inside, a double charge will be given to the outside. The use of the inner can, however, renders it unnecessary to discharge the lid.

Lesson V.—Electrification by Friction—
(*Continued from Lesson I.*)

5. *Apparatus.*—(1.) Glass rod, ebonite, electroscope, etc. (2.) A number of different insulators, such as flannel, sealing-wax, paraffin, gutta-percha, etc. (3.) The small electrical machine described below.

Experiment I.—Both kinds of Electricity are produced by Friction.—The rubber of amalgamed silk or fur is usually not a good insulator, so that its charge is generally lost when held in the hand before its electrification can be tested. To exhibit the electrification of the rubber, place the pad of silk or fur on the cap of the electroscope, and rub the silk or fur by means of the glass rod or rod of ebonite. Examine the nature of the electricity

with which the electroscope becomes charged. It will be found to be of the opposite kind to that of the glass or ebonite. Test in this manner the quality of the electrification produced with different materials, and verify the following table, in which the substances are arranged in such an order that any substance in the list becomes negative if rubbed with a body that precedes it, but positive if rubbed with a body that follows it in the list.

TABLE B.[1]

SHOWING ORDER OF ELECTRIFICATION.

Catskin.	Sulphur.	Resin.
Glass.	Flannel.	Gutta-percha.
Silk.	Cotton.	Metals.
The hand.	Shellac.	Gun-cotton.
Wood.	India-rubber.	

Additional Practical Exercise.—Make a collection of different substances and arrange them, by means of tests made by the electroscope, in the order of electrification.

Experiment II.—Both kinds of Electricity are produced by Friction in Equal Amounts.—This may be shown by rubbing two bodies together within an insulated chamber connected with an electroscope. There should then be no external sign of electrification. A simple apparatus, such as is shown in Fig. 8, may be used for this purpose. A is a tin can embedded in a block of paraffin (B) that is protected by the wooden base. Within A is a smaller can (C), not necessarily metallic, but for purposes of convenience made of tin, cemented to the bottom of A by means of paraffin. The inside of C is lined with fur. A metal rod is soldered to the bottom of C. An ebonite cylinder (E) is supported by the metal rod so that the ebonite may easily be rotated, rubbing against the fur as it does so. The

[1] The order in the above table is liable to change, depending upon the exact composition and the nature of the surface of the substance.

outer tin can is connected with an electroscope by means of the hook S. On rotating E *no effect* is observed until it is withdrawn to the outside of the outer vessel, when the

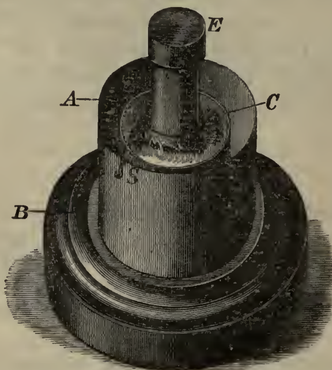


Fig. 8.

electroscope will indicate positive electricity, for the positive electricity developed on the fur decomposes the neutral electricity of the outer can, pulling the negative to itself and sending the positive away to the electroscope.

Lesson VI.—Effect of a Conducting Enclosure.

6. *Apparatus.*—(1.) A tin can sufficiently large to contain an electroscope. It should be provided with slits, opposite to each other, to enable an electroscope to be observed when placed within. (2.) Two electroscopes. (3.) Block of paraffin, conducting wire, etc.

Experiment I.—There is no Electrification within a Conductor.—Place the small gold-leaf electroscope within the tin can. Carry a wire from the electroscope to the inner surface of the can. The tin must be placed on a block of paraffin

and have its outer surface connected with a second electroscope (Fig. 9). Now electrify the tin can, when the electroscope A will immediately show the presence of electricity, while the electroscope B will not be affected. It will be

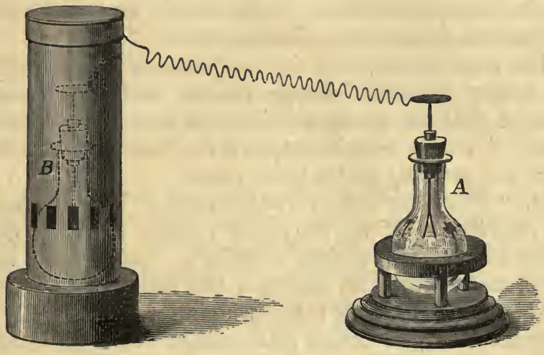


Fig. 9.

found that however intense the electrification of the outer vessel may be, the electroscope B will show no signs of electrification.

Experiment II.—Protection from External Influence.—Disconnect the wire from the inner surface of the tin can. Give the electroscope B a charge by means of an electrophorus. Now electrify the tin. No further effect will be perceived on the electroscope within the can. In this way it is shown that a body within a metallic enclosure has its electric state uninfluenced by electrifying the enclosure from without. And further, if you bring an electrified body near the outside of the can it can likewise be shown that the electroscope in the interior will be quite uninfluenced by its inductive action. This has important practical applications, as we shall afterwards see.

SUMMARY OF LAWS.

7. By aid of the preceding experiments the student has been enabled to illustrate the following laws.[1]

I. "*The total electrification of a body or system of bodies remains always the same, except in so far as it receives electrification from or gives electrification to other bodies.*"

The more we improve the insulation of a charged body the longer does the charge remain, and it is therefore assumed that an absolutely isolated charge remains constant. A charge may be retained for years in a chemically dried, hermetically sealed glass vessel.

II. "*When one body electrifies another by conduction the total electrification of the two bodies remains the same, that is, the one loses as much positive or gains as much negative electrification as the other gains positive or loses negative electrification.*"

This may be proved by bringing two unequally and differently charged bodies into contact within an insulated enclosure connected with an electroscope, when it will be found that the divergence of the leaves of the electroscope will be the same after contact as before it.

III. "*When electrification is produced by friction or by any other known method, equal quantities of positive and negative electricity are produced.*"

This is illustrated by Experiment II., Lesson V.

IV. "*If an electrified body or system of bodies be placed within a closed conducting surface, the interior electrification of this surface is equal and opposite to the electrification of the body or system of bodies.*"

In the case of an electrified body placed in the laboratory or other room where the experiment is performed, the floor, walls, ceiling, etc., take a charge equal and opposite to that of the body.

We see this from the analogy of Experiments I. and II.,

[1] *Elementary Treatise on Electricity*, by J. Clerk Maxwell.—Clarendon Press.

Lesson IV., in which the inside of the tin can was found to contain electricity opposite in character but equal in amount to that of the electrophorus lid.

V. "*If no electrified body is placed within the hollow conducting surface, the electrification of this surface is zero. This is true not only of the electrification of the surface as a whole, but of every part of the surface.*"

This is seen from Experiment I., Lesson VI., in which no effect is produced upon the electroscope within a tin can by electrifying the outside of the can.

8. *Fundamental Quantitative Law.*—If we add to the above five fundamental laws of electric phenomena a sixth quantitative law, the student will be placed in possession of all that is necessary to explain elementary electrostatics. Suppose that at a point A there are m units of positive electricity, and at B m' units of the same kind of electricity, and let the distance between A and B be d centimètres, then it is found that the force f of repulsion may be represented thus,

$$f = \frac{mm'}{d^2} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If the electrification at A or B be negative, this is indicated by putting a minus sign before the symbol of quantity. Thus if A be charged with $+3$ units and B with -6 units at a distance apart of 2 cm., then

$$f = \frac{(+3) \times (-6)}{2^2} = -4\tfrac{1}{2}.$$

A negative sign, therefore, denotes attraction. The direct proof of the very important law in formula (1) is experimentally difficult. It was first attempted by Coulomb by using a torsion balance.

9. *Definition of the electrostatic unit of quantity of electricity.*—The above expression (1) will enable us to define the electrostatic unit of quantity. Let $f = 1$, $d = 1$, and

$m = m'$, then must $m = 1$; in other words, when A and B are each charged with an electrostatic unit of electricity, and are placed unit distance apart, then will these points tend to separate with the unit of force. The unit of force which we shall adopt is the *dyne*, and this will be afterwards defined.

FURTHER THEORETICAL NOTES.

10. *Potential—Difference of Level.*—Every one knows what is meant by *difference of level.* When we say that the surface of one pond is 100 ft. and that of another pond 50 ft. above the level of the sea we convey perfectly definite information. It will nevertheless be of importance to examine minutely what is and likewise what is not implied in this very simple statement. In the first place *it is implied that all parts of the surface of the one pond are at the height of* 100 *ft., and all the parts of the surface of the other pond at the height of* 50 *ft. above the zero or sea-level.*

The various parts of each pond are thus in a condition of equilibrium, and there is no rush of water from one part to another of the same pond.

In the next place, *it is not implied that all parts of the same pond have the same depth of water.* On the contrary, some portions may be very shallow and others very deep without in the least affecting the equilibrium.

Again, the one pond may be very different in size from the other, and it may be necessary to take a very large amount of water out of the one in order to reduce its level by 1 ft., while it may be necessary to take only a small quantity out of the other to bring about the same result.

We may define this difference by saying *that the capacity of the first pond is much greater than that of the second.*

In order to simplify our conceptions, let us imagine that the two ponds are—the one at the top and the other at the bottom of the same vertical wall, and that on this wall we have a machine by which we may raise water from the lower to the higher level. It is clear that every pound of water so conveyed must be raised 50 ft. in vertical height, so that, according to the British terminology, 50 *foot-pounds of work* must be spent in carrying *one pound*

of water from the lower level to the higher; at least this is what will happen at the beginning of the process, and before we have sensibly affected the level of either pond.

11. *The Foot-Pound, Dyne, and Erg.*—We may at once generalise this statement by asserting that the *work which we must spend in conveying* m *pounds of water from one level to another* d *feet above it will be* md *British units of work, or foot-pounds as these units are called.* On the other hand, we may open up a channel between the higher and lower ponds, and the falling water may be made to do useful work; and here too we may generalise by asserting *that* m *pounds carried down the channel through* d *vertical feet will do useful work equal to* md.

When we speak of foot-pounds we virtually assume the attraction of the earth for one pound to be our unit of force, and the foot to be our unit of length. Such well-known units are of essential preliminary service in enabling the student to realise a natural force, such as gravity, and to give him a clear conception of energy and work. Nevertheless, it is highly desirable for many reasons, in the various branches of physics to make use of the centimètre, gramme, and second system of units, commonly called the C. G. S. system.

In this system, while the second still remains the unit of duration, the centimètre is the unit of length, and the gramme the unit of mass. The unit of force, called the *dyne*, is that which, when acting on unit of mass (one gramme) for unit of time (one second), will generate unit of velocity (that of one centimètre in one second).

In this system likewise the attraction of the earth for one gramme will be represented by 981, inasmuch as gravity acting on one gramme for one second will generate in it the velocity of 981 cm. per second.

Finally, the unit of energy is called the *erg*, and it represents the energy required to move a body against unit force (the dyne) through unit distance (the centimètre). If, therefore, we raise a gramme through one centimètre of vertical height against gravity we exert an amount of energy = 981 ergs.

12. *Comparison of Electricity and Gravity.*—Now there may be

difference of level in the case of electricity just as truly as there is for gravity; and just as water, when we open up a conducting channel, will run from a higher to a lower level, so in electricity, when we connect together by a wire two electrified bodies at different electrical levels, will there be a rush of electricity from the one to the other.

But while there is in many respects a very great likeness between gravity and electricity, there are yet features of difference which must be borne in mind.

In gravity we naturally associate difference of level with difference in vertical height, so that you could not have two reservoirs of water with their surfaces quite close together and yet possessing great difference in level. On the other hand, in electricity (as for instance in the outside and inside coatings of the Leyden jar) you may have two surfaces at very different electrical levels, and yet very close together. In fine, we must entirely dismiss from our minds the idea that the foot-rule will give us the means of measuring differences of electrical level. Even in the case of gravity, the method of measuring differences of level by the foot-rule, although practically convenient, is by no means theoretically perfect.

As a matter of fact, we cannot leave the surface of the earth, but in imagination we may transport ourselves to a distance ten times as far from the earth's centre as is our present abode. We may likewise take with us a pound of water, and at this great distance from the earth's centre raise it up vertically 1 ft., just as we might do on the earth's surface. It will not, however, cost us so much labour to do this at the increased distance as it would at the earth's surface, because at the former position the force of gravity would have only $\frac{1}{100}$ part of its present or earth-surface value. Hence we might at the increased distance raise the pound of water 100 ft. with the same expenditure of energy that would be required to raise it 1 ft. at the earth's surface.

So then we see that there may be two ways of measuring differences of level, namely the practical but unscientific method by the foot-rule, and the unpractical but yet eminently scientific method by taking account of the work spent in carrying a pound weight from the one level to the other.

If we adopt this latter method of procedure, we should regard unit difference of level at the earth's surface to be 1 ft., but at the increased distance 100 ft.

Viewed in this manner, differences of level are known as *differences of potential.* Two points therefore may be said to be at unit difference of potential as regards terrestrial attraction when unit of work is spent in conveying unit of mass (the pound) from the one point to the other. It appears that we thus get hold of a general conception which will serve us far above the earth's surface if we agree to measure differences of potential or level by the test of work and not by that of the foot-rule.

13. *Equipotential Surfaces.*—Suppose now that we have a number of points all at the same potential or level, it is clear that no work will be required in order to carry 1 lb. from one of these points to another. A surface passing through such points is called an **equipotential surface.** The surfaces of the two sheets of water of which we have been speaking are equipotential surfaces, the potential of the one being, however, different from that of the other by 50 units. Also the potential of the one surface is 50 and that of the other 100 units different from that of the sea surface, which we may call our *zero of potential.*

But further, this new way of looking at things will not merely serve us as we go from the earth's surface to distant regions, but it will likewise serve us when we go from one force to another—from gravity to electricity, for instance, being just as applicable to the one as it is to the other.

In gravity, we say that two points are at unit difference of potential when unit of work is spent in carrying unit of mass from the one to the other against gravitating force. So in electricity we may say that *two points are at unit difference of electric potential when unit of work is spent in carrying unit of electricity from the one to the other against the force of electric attraction or repulsion.* Our readers will remember that unit of electricity has been already defined (Art. 9).

14. *Zero of Potential.*—Now when we open up, by means of a wire, communication between electrified bodies at different

potentials, there will be a rush of electricity from the body of highest to that of lowest potential. If, however, we open up a communication between two bodies that are at the same potential, there will be no transfer of electricity between the two.

And, just as in the case of gravity, we take the sea-level to be the zero or standard level or potential, so *in the case of electricity do we take the potential of the earth to be the zero potential.* It follows that when a body has a higher positive potential than the earth there will, when communication is opened, be a rush of positive electricity from that body to the earth ; and that when a body has a lower positive potential than the earth there will be a rush of positive electricity from the earth to that body. This last is the same thing as saying there will be a rush of negative electricity from the body to the earth.

Note.—To ascertain the nature of the potential of a body we may further consider whether, when a small imaginary charge of positive electricity is transferred from the body to the earth, this operation is favoured or resisted by electrical force : if the former, the potential is positive ; if the latter, the potential is negative.

15. *Positive Current only considered.*—We shall not here consider as distinct things this rush of positive electricity from the earth to the body and this rush of negative electricity from the body to the earth ; these may be regarded as merely two ways of viewing the same transfer, and in this science of electricity we shall agree to consider only the flow of positive electricity.

Note.—We do not intend to discuss whether there are two sorts of electricity or only one sort. But we shall assume, for convenience sake, that the former assumption is the true one. The student must then bear in mind that an isolated body *distant from other charged bodies* is

(1.) Of + potential if of + charge.
(2.) Of − ,, ,, − ,,

But if the body is near others, there is no such simple connection between the nature of the charge and the potential. This will be seen in subsequent experiments.

16. *The Units of Density and Capacity.*—We have thus defined unit quantity of electricity and unit difference of potential or

electrical level, and it will now be very easy to define unit density and unit capacity. If *unit of surface of a conductor has on it unit quantity of electricity, then we say that the electrical density of that surface is unity.* So that the density is measured by the number of units of quantity that exist on one square unit of surface.

Again, *if it takes unit quantity of electricity to raise the electrical level of a conductor one unit, then that conductor has an electric capacity equal to unity.* So that the electric capacity of a conductor is measured by the number of units of quantity required to raise it through one unit of potential.

So in like manner we might say that if it requires unit of mass, or 1 lb. of water, to raise the level of a vessel of water 1 ft., then the vessel has unit capacity. But if it requires 2 or 3 lbs. of water to do this, then the vessel has a capacity represented by 2 or 3.

17. *Application of Definitions.*—The analogy derived from gravity may likewise be used for enabling us to perceive the solution of a great number of electrical problems. Suppose, for instance, that we have a vessel of water, the capacity of which is unity—that is to say, it requires 1 lb. of water to raise its contents 1 ft., and that it is required to find what expenditure of energy will be necessary in order to fill it, say to the height of 6 ft. Here it will be evident that the first portions of water put into the vessel have only to be raised to a comparatively small height, while the last portion has to be raised to the whole height of 6 ft. It follows that the whole energy necessary to raise the level 6 ft. from the bottom will be that necessary to raise 6 lbs. of water through the *average* height of 3 ft.—that is to say, 18 foot-pounds or British units of work.

We may generalise, and say that if we have a vessel whose capacity is C, and if we fill it to a height H, the necessary expenditure of energy will be

$$\mathrm{CH} \times \frac{\mathrm{H}}{2},$$

the first, or left-hand factor, representing the whole quantity of water necessary, and the second, or right-hand factor, the aver-

age height through which this water has to be raised. In like manner, if we have an electrical conductor of capacity C, and we wish to raise it to the potential or electrical level represented by V, we must expend upon it a quantity of energy represented by

$$CV \times \frac{V}{2},$$

in which the left-hand factor denotes the whole quantity of electricity required to perform this operation, and the right-hand factor the average height above the earth-level, or zero, through which it has to be raised against the action of electrical forces.

Our readers might like to know why we have used the letter V to denote electric potential. It is in compliment to Volta, the eminent electrician, V being the initial letter of his name. In like manner C is the first letter of the word *capacity*, and H the first letter of the word *height*.

18. *Condensers.*—Sometimes the word condenser is used instead of conductor when speaking of a metallic surface charged with electricity. This word is used more especially to denote an arrangement where we have two metallic plates near one another, with a *dielectric*, such as air, glass, or ebonite, between. Thus the Leyden jar is a condenser, the internal coating of which may be supposed to be at the potential of the prime conductor of the electrical machine which charges the jar, while the external coating is at *zero* potential, being held in the hand during the process of charging, and thus having the same electrical level as the earth. A condenser may thus be said to consist of two metallic plates near each other, with a dielectric between, these two plates being at different potentials. It must not, however, be imagined that a system of this kind is essentially different from that which represents an insulated charged conductor. Here in reality we have two conductors, just as truly as in a condensing system, the outer conductor being the metal, human bodies, and other conducting substances which surround the inner insulated conductor, the air between acting the part of a dielectric. Hence, if the insulated conductor be charged with a certain amount,

say of positive electricity, we shall have on the surrounding conductors, according to the experiment of Lesson IV., an equal quantity of negative electricity.

18*a*. *Definition of Specific Inductive Capacity.*—The coefficient by which the capacity of an air condenser must be multiplied in order to represent its capacity when another dielectric is used is called the **specific inductive capacity of the dielectric.**

19. *Discharge of a Condenser.*—When we discharge a condenser, such as a Leyden jar, by bringing the opposite plates into communication with each other, the energy of electrical separation of the jar is converted into heat; and the amount of heat produced will be represented by the energy that was expended in charging the condenser, which is now discharged. This energy will be, as we have already seen,

$$CV \times \frac{V}{2} = \frac{CV^2}{2} = \frac{(CV)^2}{2C},$$

where C is the capacity of the condenser and V the potential of its inner surface, the outer surface being supposed to be at zero potential. Now the quantity of electricity which has been put into the condenser is CV, and hence we see from the above formula that for the same condenser the heat produced by the discharge will be proportional to the square of the quantity of electricity which has been put into the condenser.

20. *Exercises.*—

1. Describe the construction of a gold-leaf electroscope.
2. Why do the gold leaves of a charged electroscope diverge?
3. How would you electrify a gold-leaf electroscope *positively* by conduction, and how by induction?
4. How would you electrify a gold-leaf electroscope *negatively* by conduction, and how by induction?
5. A gold-leaf electroscope is charged and an excited stick of sealing-wax is brought down slowly towards its plate from a distance above. At a certain point the gold leaves collapse, but when the stick is brought still nearer they again diverge. Explain this behaviour.
6. A charged electrophorus with its lid on is placed on the top of a gold-leaf electroscope. The lid is touched by the finger, when the leaves of the electroscope will be found to diverge. Explain this.

7. An insulated tin can is charged and an insulated conductor is introduced into the interior and there allowed to touch the can. When taken out it is not electrified. Explain this.

8. An insulated tin can is charged and a conductor connected with the earth is introduced into the interior, and there allowed to touch the can. What will be the result, and how is this result to be explained?

9. How many *dynes* represent the force with which the earth attracts a one-pound weight?

10. How many *ergs* go to represent one foot-pound of energy?

11. An electrified point attracts another point oppositely and equally electrified with the force of 8·5 dynes when the two are 5·3 centimètres apart. How many units of electricity are at one of these points?

12. A point is charged with 6 units of positive electricity and another with 4 units of negative electricity, and the two are 7 centimètres apart. With what force will they attract each other?

13. A conductor of capacity 5 has been charged up to the potential 6. How much energy has been expended upon it in the process of charging?

Lesson VII.—Experiments on Potential with Electroscope.

21. *Apparatus.*—We shall in the lessons which follow require a special electroscope, which may also be used as a rough electrometer. Fig. 10 shows a form of this instrument possessing the advantage of excellent insulation, and of having its leaves protected from electrification of the glass enclosure, a fault to which the electroscopes that we have hitherto used are liable. The present instrument consists of a glass cylinder, provided with a cork C that supports an arm of glass rod gg', bearing a small block of ebonite e. Through a hole in e there passes a brass wire w stiff enough to be adjustable. This wire bears at one end the gold leaves, which are very narrow, and at the other a small knob k. In the cork C is a hole h, much larger than the diameter of the brass wire. Thus w is supported and insulated entirely by the glass rod and ebonite block, and has no contact with the cork C. To keep the glass stem dry, at the bottom of the cylinder there is placed asbestos, a, moistened with strong sulphuric acid,

which is kept in place by a perforated leaden sheet *l*. When the instrument is not in use a small cork S is made to slide down *w*, and so as to stop the hole in the large cork.

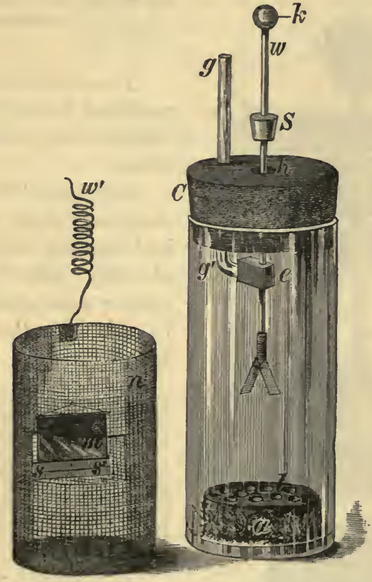


Fig. 10.—GOLD-LEAF ELECTROMETER.

To shield as much as practicable the instrument from external electrification, a cylinder *n* of copper wire-gauze, open at the top and bottom, just fits within the electroscope. (In the figure this is shown removed for the sake of clearness.) A square window is cut in this gauze for the observation of the leaves, and in order to observe their distance apart a piece of mirror glass *m* with a scale *ss'* attached is fastened to the gauze. To enable contact to be made with the gauze a wire *w'* is provided.

Note.—Another form of the electrometer, made out of a tin canister,[1] is shown in Fig. 10*a*, which is lettered to correspond with Fig. 10. The glass *gg′* passes through an india-rubber cork *t*. The front of the can is a window D, having cross bars of tinfoil. At *a* is the asbestos within a leaden tray.

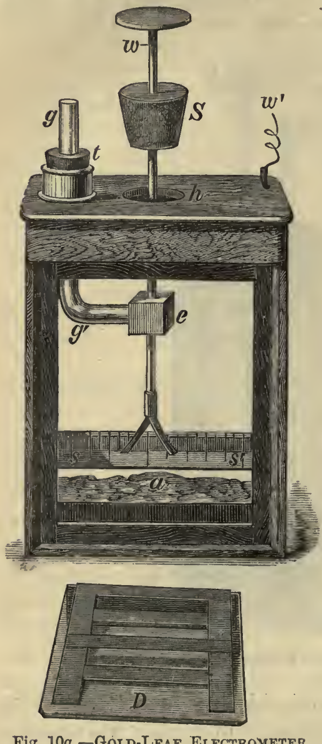


Fig. 10*a*.—Gold-Leaf Electrometer.

The remaining apparatus required is an ebonite rod, catskin, and a block of paraffin.

Experiment I.—Place the electroscope on the paraffin and connect w and w'. Now electrify the knob. No matter what charge is given to this, the leaves will remain closed.

Explanation.—(1.) Both leaves and screen are at the *same potential*, since they are connected together. (2.) Between bodies at the same potential there is no electrical force.

Experiment II.—Disconnect w and w', and connect the screen with the earth, while we leave the knob insulated and discharged. Now charge w, the leaves diverge.

[1] The tin canister corresponds to the screen of wire-gauze of Fig. 10. It should be noted that in a theoretically perfect electroscope or electrometer the screen would wholly surround the leaves, which then would be completely protected from external electrification. Seeing, however, that the instrument is often required to test external charges with which a wire must communicate, such perfect protection is not possible.

Explanation.—We raise the potential of the knob and therefore of the leaves by a certain amount above that of the screen.

Experiment III.—Now insulate the screen and charge it by successive small charges of the same kind; the leaves gradually close. Continue to charge w'; the leaves again open.

Explanation.—(1.) They collapse, because the series of small charges has brought the potential of the screen equal to that of the leaves. (2.) They open again, because the potential of the screen has been increased, so that now there is a difference between it and the leaves.

The preceding experiments will have taught the student the true meaning of the indications of the electroscope.

Lesson VIIa.—The Condenser.

21*a*. *Apparatus.*—A well-insulated plate condenser will be requisite. One form is shown in Fig. 11. Here A and B are two brass plates, with rounded edges, supported from glass stems y and y' by means of metal collars b and b'. These stems are kept dry by being surrounded by glass cylinders g and g', containing asbestos and sulphuric acid at a and a'. A block of lead L with a central hole serves to support the glass stem y', which passes through a hole h (but without touching) in the cork C. Two corks s and s' keep out dust when the instrument is in use, otherwise they are raised so as to be free from the cylinders.

Note.—In a later and better form of the instrument the plates A and B are vertical and supported on wooden bases. The glass stems are kept dry by asbestos and sulphuric acid contained in annular leaden cups surrounded by glass tubes. This form has the advantage that the plates may be slid any distance apart, whereas in Fig. 11 the upper plate A must either be separately supported, or pieces of ebonite must be used to keep the plates apart. One advantage of the form (Fig. 11) is that the horizontal plate B forms an excellent insulating stand.

Two gold-leaf electroscopes, which had better be of the type last described. Ebonite rod and fur. Glass rod and silk. Block of paraffin.

Experiment I.—Put the plates nearly in contact, and connect A with the cage and B with the knob (Fig. 11*a*) of the electroscope, which should be insulated on a block

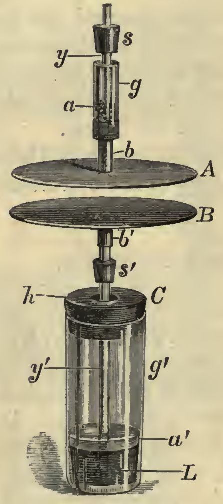


Fig. 11.—The Condenser.

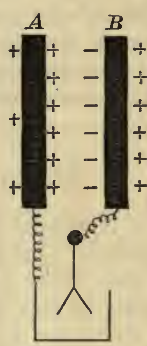


Fig. 11*a*.

of paraffin. Give a + charge to A until the leaves open a little. Now separate A and B, when the leaves will open more and more widely the farther the plates are asunder.

Explanation.—B, an insulated body within the field of force of A, is at a positive potential. A proof of this will appear from the fact that if B be connected with the earth *positive* electricity will flow from it to the earth (see next experiment). Also the positive potential of B is greater

the nearer it is to A, and the potential of A decreases with the approach of B, and hence the difference of potential between A and B increases the farther that they are separated.

Notes (1.) On B there is both $-$ E and $+$ E, but the whole plate B is nevertheless of one potential.

(2.) The arrangement A and B is a condenser whose capacity becomes less as A and B are separated. Now the relation Q (quantity of electricity) $=$ CV (see Art. 17) must be fulfilled, and since Q is constant, V (the difference of potential between A and B) must increase as they are separated.

Experiment II.—Use two electroscopes, and make the connections of Fig. 11*b*. Give A a $+$ charge. B will be found to have a $+$ potential.

Explanation.—A is of a $+$ potential, B, a body in its field, is likewise of a smaller yet $+$ potential (see Art. 15).

Experiment III.—Touch B so as to connect it with the

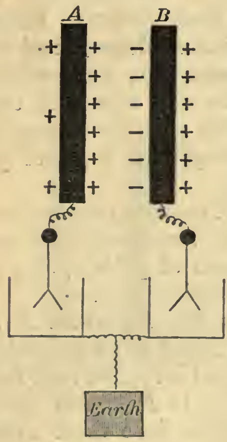


Fig. 11*b*.

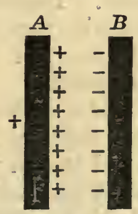


Fig. 11*c*.

earth. The electroscope, connected with B, shows no charge, and that connected with A is deflected less.

Explanation.—The condition of things is as shown in

Fig. 11*c*. A has a + charge and B a − charge. The charge of B under these conditions is said to be "bound." It cannot leave B, inasmuch as it is at zero potential. But the presence of B in this condition lowers the potential of A.

Experiment IV.—Let B be still earth-connected, and approach it nearer A; the electroscope of A now shows a diminished deflection. Remove it farther from A, the deflection increases.

Explanation.—This is left as an exercise.

LESSON VIIB.—Comparison of Condensers by Cavendish's Method[1]—Specific Inductive Capacity.

21*b*. *Apparatus.*—The insulated condensers of Lesson VIIA. Gold-leaf electrometer. Electrophorus. Ebonite insulating supports. Two cylindrical condensers, each consisting of a tin can within an outer can, from which it is insulated. The interspace in the case of one of the cans is filled with paraffin. Graduated scale for measuring the distance apart of the condenser plates. Block of paraffin for insulation.

Method and Theory.—It will be necessary for two students to work together in order that the connections may be made and broken without the use of pulleys, etc., as employed by Cavendish. The operations are :—

1*st*, Make connections as in Fig. 12, where A and B are the condenser plates, C and D the inner and outer cans of the cylindrical condenser, *a* and *b* ebonite rods for holding the connecting wires. Give to A several sparks by means of the electrophorus. Now since there exists the same difference of potential (V) between the coats of the

[1] The student is referred to *The Electrical Researches of the Honourable Henry Cavendish, F.R.S.* Edited by J. Clerk Maxwell. This interesting record of important scientific work, done with crude apparatus, should find a place in every scientific library.

two condensers, if we call K the capacity of the plate condenser and K′ that of the cylindrical condenser, then the

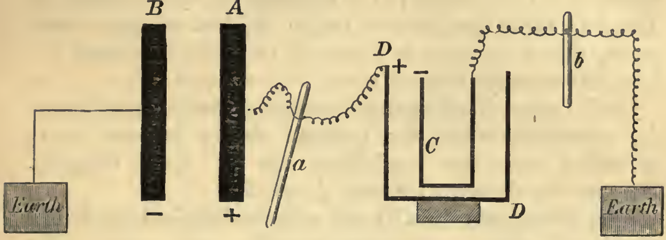


Fig. 12.

amount of electricity (Q and Q′) with which each condenser is respectively charged is

$$Q = KV,$$

and

$$Q' = K'V.$$

2nd, Now alter the connections to those of Fig. 12*a*.

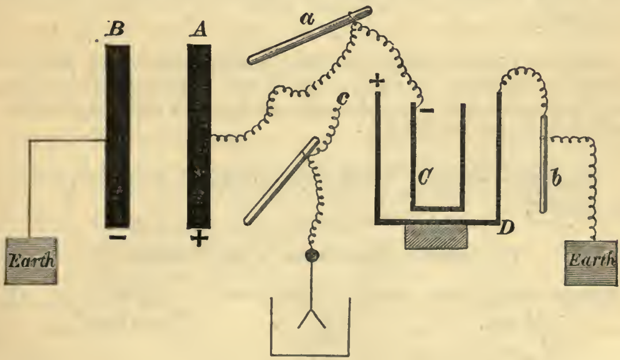


Fig. 12*a*.

What will then happen? The quantity of electricity Q will mix with that on C, which is of quantity Q′ but of

opposite sign to that on A. If $+Q = -Q'$ the neutralisation will be complete, and on bringing an electroscope, by means of an insulating rod *c*, to touch the wire connecting A and C, there then should be no residual charge. Supposing that a – charge is obtained, then the condenser AB is of less capacity than CD.

3rd, Lessen the distance between A and B, and repeat the operations until the residual charge becomes zero, in which case the condensers are of equal capacity. Measure the distance between A and B.

4th, Substitute for CD the other cylindrical condenser mentioned above, containing paraffin, and again adjust the plate condenser, and measure the distance apart of A and B.

If we divide the distance apart of the plates in the first case by that in the case where the cylindrical condenser contained paraffin, the result will denote the ratio of the capacities of the two cylindrical condensers, and the same number will be the specific inductive capacity of paraffin.

Note.—We have assumed that the distance apart of the plates is inversely proportional to the capacity of the condenser. This is not strictly the case, but if the distance apart is not great, it is sufficiently true for our experiments.

Example.—Source of charge one spark from large electrophorus.

CYLINDRICAL CONDENSER WITH PARAFFIN.

Distance apart of Plates.	Reading of Electrometer.	Result.
12·5 mm.	– 50	Plates least.
10 ,,	·30	,, ,,
7·5 ,,	– 20	,, ,,
5 ,,	– 16	,, ,,
3 ,,	+ 2	,, greatest.
2·5 ,,	+ 10	,, ,,

Capacity = that of plates 3 mm. apart nearly.

CYLINDRICAL CONDENSER WITH AIR.

15 mm.	−40	Plates least.
12·5 ,,	−25	,, ,,
7·5 ,,	−14	,, ,,
5 ,,	+12	,, greatest.
6 ,,	+ 1	,, ,,

Capacity = that of plates 6 mm. apart nearly.

Hence, specific inductive capacity of paraffin

$$=\frac{6}{3}=2.$$

LESSON VIIc.—Comparison of Conducting Powers of Oils.

21*c*. *Apparatus.*—Condenser. Gold-leaf electrometer. An ebonite cup to hold oils, provided with two binding screws. Electrophorus.

Method.—When a charged condenser has its plates connected through a bad conductor, the condenser slowly discharges itself. If an electrometer be connected with the condenser, and the times observed that the condenser, with different bad conductors, takes to fall from a given potential to a lower given potential, then their conducting powers will be in the inverse ratio of the observed times.[1]

The requisite connections are shown in Fig. 12*b* for the experiment, which requires two observers. The plates A and B of the condenser are placed very near together. The cup of ebonite *e* at first must be empty. A charge is given to A, and then one observer watches the leaves of the electrometer, his eye being in such a position that their reflected images are covered by the leaves. (This is necessary in order to avoid the error called parallax.) When the deflection reaches a certain amount, the electrometer observer makes a sharp tap on the table, and the second observer notes down the time to a second. The first

[1] For the complete formula see *Elementary Practical Physics*, vol. ii. p. 438.

observer continues to watch the leaves, and when the deflection reaches about half the first value a second time-signal is made, and the second observer will now know the time that the condenser has taken to leak from the higher to the lower potential. If the period is a long one, it

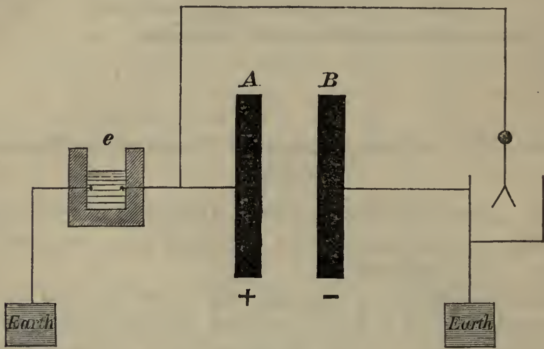


Fig. 12*b*.

shows that the insulation of the apparatus is satisfactory, and the cup may be filled with oil. On repeating the experiment the leakage will be found much greater, so great, in fact, that the leakage without oil in the same time may be considered quite negligible. In the same way various oils should be tested.

Example.—Leakage from 40 to 20 divisions.

No. of Experiment.	Paraffin Oil.	Olive Oil.
1	32 seconds.	15 seconds.
2	35 ,,	15 ,,
3	30 ,,	61 ,,
4	38 ,,	15 ,,
5	33 ,,	15 ,,
6	33 ,,	14 ,,
	Mean, 33·5 seconds.	Mean, 15 seconds.

Hence

$$\frac{\text{Conducting power of olive oil}}{\text{Conducting power of paraffin oil}} = \frac{33{\cdot}5}{15} = 2{\cdot}2.$$

CHAPTER II.

MAGNETISM.

22. A MAGNET, for the purpose of this work, may be considered to be a piece of steel or iron that is capable of attracting steel or iron. Every magnet has two *poles*, where the magnetism appears strongest. The line joining these is called the *magnetic axis*. A freely-suspended magnet balanced so as to swing horizontally sets itself in such a manner that its axis will lie in a direction known as the *magnetic meridian*. This direction makes, at a given place and time, a definite and generally small angle with the geographical meridian. With reference to this position assumed by the magnet, that pole which points nearly north is generally called the north pole, and that which points nearly south the south pole; but other names have been given to these poles, as will be seen from the following table :—

TABLE C.

NAMES OF POLES.

Pole that points to the North, or North-seeking.	Pole that points to the South, or South-seeking.	
North	South . .	Ordinary usage.
Austral	Boreal . .	French usage.
Marked	Unmarked. .	Faraday.
Red	Blue . . .	Sir G. Airy.
True South	True North .	Sir Wm. Thomson.
Positive (+)	Negative (−) .	Mathematical usage.

We shall in this volume use the letter N or the sign + to denote the north-seeking, and the letter S or the sign – to denote the south-seeking pole of the magnet.

Lesson VIII.—Fundamental Experiments.

23. *Apparatus.*—Bar and horse-shoe magnets with their poles marked, some thin knitting needles, pieces of watch-spring, soft iron nails, silk fibre, test tubes with corks, blowpipe, Bunsen's burner, sealing-wax varnish, steel filings, a bar of very soft iron, No. 20 iron wire, a strip of tinned iron, various specimens of steel and iron, and two binding screws.

First fit up a delicate instrument for indicating the presence of magnets and magnetic bodies. We shall call this instrument the *magnetoscope.* Let us first heat a piece of watch-spring in the blowpipe flame to bright redness, and then plunge it quickly into a beaker of cold water. The watch-spring will now be found to be hard and brittle. Next break off a piece a little shorter than the breadth of the test tube, and then proceed to magnetise it by rubbing it always in the same direction on one of the poles of the bar magnet. Fit into the open end of the test tube a cork provided with a glass tube terminating in a crook, as shown in Fig. 13.[1] Now proceed to attach a very fine silk fibre to the small piece of magnetised watch-spring, which may be done with the help of a little beeswax. The magnet should hang horizontally when suspended by the silk fibre. In order to secure

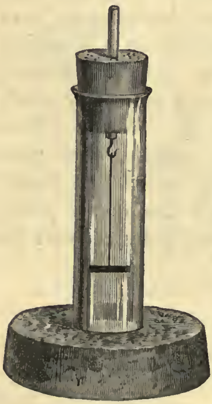


Fig. 13.
The Magnetoscope.

[1] Instead of a test tube a bottle may be used.

this position a little sealing-wax varnish may be put on one end—the varnish serving the double purpose of perfecting the horizontality of the magnet and of distinguishing the one end from the other. Attach the other end of the fibre to the glass hook, and place the suspended system in the test tube. The test tube may be supported by a large cork, through which a hole has been bored to admit the end of the tube.

With the aid of this instrument and the above materials let the student perform the following experiments :—

Experiment I.—Show that like poles repel and unlike poles attract each other—the north pole of the experimental magnet being that end which points to the north.

Experiment II.—Magnetise a piece of the brittle watch-spring by drawing it across the N. pole of a magnet. Notice that the end of the piece of watch-spring which *last leaves the pole* of the magnet is a S. pole. Show that when broken into two parts each portion of this remains a perfect magnet. Show also that however often the process of breaking is repeated, the above result will ensue, each portion remaining a perfect magnet.

Experiment III.—Show that a test tube filled with filings or turnings of hard steel may be magnetised just as if it were a steel bar. Then show that if the turnings are taken out, mixed together, and replaced, they are no longer a magnet. To magnetise the filings a strong magnet should be used.

Experiment IV.—Anneal a piece of soft iron wire by heating it to redness and allowing it to cool slowly, then show that this wire attracts both ends of the magnet. A body which attracts *both ends* of the magnet is said to be a *magnetic* body.

Experiment V.—Attempt to magnetise the soft iron wire by drawing it across the pole of a magnet ; when withdrawn it will be found that at the most only a very feeble magnet is produced.

Experiment VI.—Show, however, that while the soft iron remains in *contact with or near* the pole of the magnet the former becomes temporarily a magnet, being capable of attracting iron filings. Show also that the portion of the soft iron in contact with, say, the N. pole possesses a S. magnetism, and that portion of it farthest from the magnetic pole a N magnetism. To verify this use a small *test needle* (A or B, Fig. 14), which you convert into a magnet by rubbing it first on the end n, so that the point of the needle leaves this end last. Then, according to Experiment II., if the bar of soft iron has its poles as marked in the figure, the needle, when drawn across the

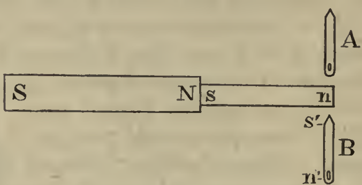


Fig. 14.

end n from position A to B, will have its point exhibiting south polarity. This is called *magnetisation by induction.*

Experiment VII.—Magnetise a piece of watch-spring. Wind a piece of wire round it so that the watch-spring may be held in the blowpipe flame, where it should be heated to a bright redness. The piece of watch-spring if tested when cold will be found to be no longer a magnet.

Experiment VIII.—Hold a bar of soft iron in a vertical position and smartly tap the upper end with a hammer. Whilst *still vertical* test the bar, when it will be found to be a magnet, the lower end being the north-seeking pole. Reverse the bar and repeat the experiment, the polarity will be found to be reversed, the now lower end of the magnet being still the north pole. Here the bar becomes

magnetised by the inductive action of the earth, which acts like a large magnet.

Experiment IX.—Instead of a bar of soft iron take a long and somewhat wide slip of ordinary tinned iron, and placing it vertical as in the last experiment, bend it backwards and forwards, causing the iron to make a noise. It will now be a magnet, the lower end being the north pole. If carried gently away and applied to the magnetoscope, it will probably be found to have retained its magnetised state; but if once more mechanically disturbed when horizontal and pointing east and west it will be found to be no longer a magnet, being now devoid of all polarity. In this state it will of course attract equally both poles of the suspended needle.

Experiment X.—Obtain a large knitting needle and clamp it firmly at the ends by the brass binding screws. Violently twist the wire when in the close neighbourhood of a magnet. The knitting needle will be found to have become permanently magnetised.

From these experiments we may learn various things.

In the first place we see that the difference between hard and soft iron consists in this, that the former is capable of retaining its magnetised condition when withdrawn from the exciting cause, while, however, the latter is unable to do so, losing all or nearly all its magnetism when withdrawn.

Now a body which, owing to molecular rigidity, does not readily lose its magnetisation is, from the same cause, less susceptible of acquiring this condition. To increase its susceptibility in this respect we promote a certain molecular freedom, either by heat or mechanical disturbance, while the body lies in a position favourable to magnetic influence. The magnetisation is thus allowed to enter, and when entered is kept there, for when the body is cooled, or when the mechanical disturbance has ceased, the particles are once more in a rigid state. A kind of trap is

thus laid for the magnetisation, this being invited to enter through an open door, which is immediately shut, so that the guest is converted into a prisoner. This property of hard iron is called *coercive force*, and from Exps. VIII. and IX. we may gather that soft iron is not entirely devoid of this property, possessing it, however, to a very much smaller extent than hard iron.

Lesson IX.—The Magnetic Field.

24. *Exercise.*—To obtain and fix magnetic curves.

Apparatus.—Bar and horse-shoe magnets, pieces of soft iron, a piece of ferrotype iron, a paraffin bath, sheets of thin writing paper, iron filings, a piece of fine muslin, and an old saw or sheet of steel.

Method I.—Melt the paraffin wax in the bath, and soak in it a sheet of writing paper. Lift the paper out of the bath by one corner and allow the melted paraffin to drain off. Suspend the paper by one corner until the paraffin has set hard. Coat several sheets in this way. Now place closely over a horizontal bar magnet a sheet of the prepared paper, which should be supported so that the surface is level by means of pieces of wood. Scatter through the fine muslin iron filings over the paper from about a foot above it. Tap the paper until the filings set themselves along lines which are called *magnetic curves.* Next pass the flame of a Bunsen's burner over the paraffin paper so as to melt the paraffin, when the filings will sink into the melted wax. On removing the flame the paraffin will soon solidify, and the filings will be retained permanently in the position which they occupied before melting — that is to say, ranged along magnetic curves. These curves may best be studied by holding the preparations up against the light, when the forms assumed by the particles of iron will be distinctly seen, owing to the translucency of the paper.

Let the student thus obtain the following curves:—

(*a*) Curves—from simple bar magnet.
(*b*) „ „ horse-shoe magnet.
(*c*) „ „ 2 bar magnets with like poles together.
(*d*) „ „ 2 bar magnets with unlike poles together.
(*e*) „ „ bar magnet with a piece of soft iron in its field.
(*f*) „ „ bar magnet near a thin disc of iron.
(*g*) „ „ end of bar magnet

It will thus be seen what is meant by the *magnetic field*. This expression merely denotes that *space all round a magnet through which it is capable of exercising an influence upon soft iron or other magnets.* The magnetic curves into which the magnetic field may be mapped out represent, in the first place, ropes or chains more or less continuous, into which the iron filings arrange themselves when they are rendered free to turn by the influence of tapping. Had we used instead of iron filings a series of very small needles free to move, these would have similarly arranged themselves along the magnetic curves, and the direction of the force acting on any one such needle would be along *the tangent to the curve* at that point. The needle would, in fact, place itself so that this force would pass along its axis, that is, it would constitute itself a tangent to the curve or be a virtual portion of the curve. A magnetic curve is therefore a line or path such that if we walk along it with a little needle in our hand this needle will always point along the path.

II. A magnet has not always its magnetism symmetrically distributed along its length. To prove this, let us obtain a long knitting needle, then, starting at a point $\frac{1}{4}$ of the whole length from one end, let us draw the N. pole of a magnet several times towards this end. Next, with the

same pole of the magnet, and starting from the same point, let us perform the same process towards the other end. In this way *consequent points* or *poles* will be produced. These will be revealed when we obtain magnetic curves from such a magnet by the process indicated above. Such a peculiar disposition of magnetism is generally, however, a source of trouble, and our object is to avoid it rather than court its production.

III. Using as a pencil one pole of a strong magnet, draw a pattern upon a thin steel plate, such as the blade of a saw, going over the pattern several times. If we then obtain magnetic curves, these may possibly be found to be very complicated. Such figures are known as *Haldat's Figures.*

Exercises.—(1.) Describe the features of the magnetic curves that you have obtained. (2.) Define *magnetic field* and *consequent points.*

Lesson X.—The Magnetic Meridian.

25. *Apparatus.*—A mariner's compass provided with sights, or the materials for making one.

Method of making a Mariner's Compass—Materials.—(1.) Square wooden box [1] about 6 cm. square and 3 cm. deep. (2.) Cardboard. (3.) Glass tubing. (4.) Mathematical drawing instruments. (5.) Sewing needles. (6.) Stocking needle. (7.) A cement, such as Canada balsam, dissolved in benzine or coaguline. (8.) Corks.

Operations.—(1.) Cut out a square piece of card so as just to fit the box. Draw on it a dial (see Fig. 15) with the thirty-two points of the compass. Cut out the shaded portion, dividing the dial into a central disc that will form the movable compass card, and an outer portion that will form the fixed index ring. The latter has marked upon it two index arrows, as shown. (2.) Make a glass cap upon which to balance the compass card. To do this draw out a piece of glass tubing (Fig. 16), close up the end by fusion, and cut off the tip of

[1] Boxes of varying size are now made for ordinary post or parcel post purposes. They are extremely convenient for the manufacture of apparatus.

the tube at *ab*. This forms the cap of the compass card, and must be inserted in a hole in the centre of the card. (3.) Make four magnets, each 4 cm. long, out of a knitting needle. Fix, by cement, two on either side of the cap, on the back of the compass card, with their axes lying parallel to the NS line (Fig. 17), with the like poles pointing in the same direction. To help in doing this accurately prick two

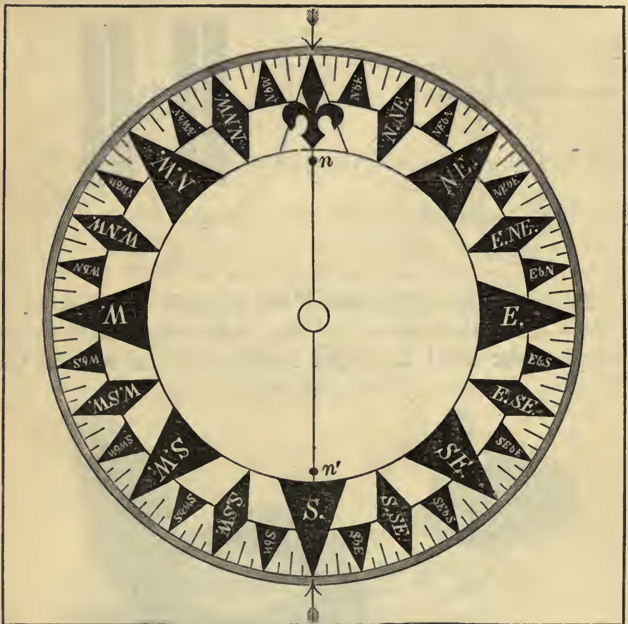


Fig. 15.

holes through the NS line, and draw a line joining them on the back of the card. Support the card on the point of a vertically-placed sewing needle, to test if it is balanced. If not, move the magnets until the card is balanced, taking care to keep the magnets parallel to the NS line. (4.) Fasten a slice of cork by cement to the centre of the bottom of the compass box, and fit upright on it a piece of sewing needle. (5.) Fix slices of cork or pieces of wood inside the box for supporting the fixed index ring, which must be fastened by

cement. (6.) Bore two holes near the top of the box at the middle of the opposite sides, through which two short glass or brass tubes t and t' (Fig. 18) must be passed. (7.) Place two fine needles nn' (Fig. 15) upright on the NS line, and near its ends. These form the *sight needles.*

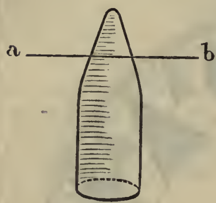


Fig. 16.

Fig. 17.

To mark down the Position of the Magnetic Meridian on the Table.—Look through one of the sight tubes and turn the compass box until the sight needles can be seen in the

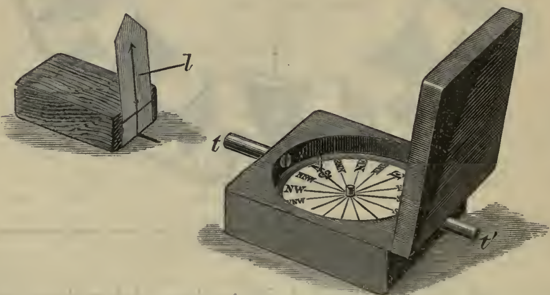


Fig. 18.—Finding Meridian.

middle of the tubes. Now support a piece of cardboard by a cork, and make upon it a black vertical line. Move this about until the line lies in the magnetic meridian, that is to say, on looking through the sight tube the black line l

(see Fig. 18) lies in the prolongation of the line joining the index needles. Make a mark on the table at the base of the vertical line, which we shall suppose to be at a (Fig. 19). Now move the cardboard back, and obtain a new position at b. The line joining a and b will be in the meridian.

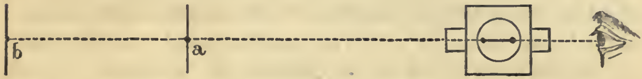


Fig. 19.

This line should be marked permanently on the table for future reference.

To find the Bearing of an Object in the Room.—Turn the compass until through the sight tubes the object whose bearing is required can be seen, then the reading of the compass card opposite the fixed mark *a* (Fig. 20) will be the bearing required.

Example.—Suppose the object to be north-east, then the position of the compass box would be as in B (Fig. 20).

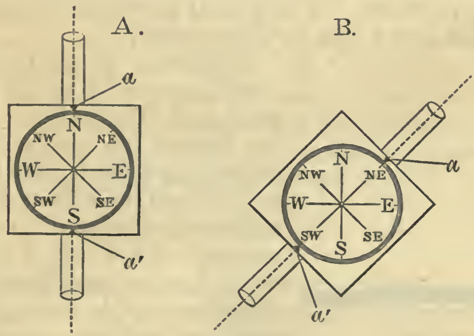


Fig. 20.

To mark down the Geographical Meridian on the Table.—Draw a line on the table, making an angle of 20° east of

the line representing the magnetic meridian. This will very nearly give the geographical meridian. The angle that the one meridian makes with the other is called the *magnetic declination.*

To verify the Geographical Meridian.—Place a stick upright when the sun is shining, and note the position of the shadow when this is shortest.[1] The shadow of the stick should now coincide with your geographical meridian line.

To illustrate the use of the Compass for finding the direction in which a ship is sailing.—A compass is fixed on board ship with the line joining a and a' lying fore and aft. Hence, when the ship is travelling due north, as in A, Fig. 20, the N of the card lies opposite a. But if the ship is travelling north-east, as in B, Fig. 20, the NE of the card will be opposite a. Thus all that is necessary is to observe the point of the card that is opposite a.

Lesson XI.—The Law of Inverse Squares.

26. *Apparatus.*—Mathematical drawing instruments, drawing board, etc. A very small compass needle mounted on a pivot and a long thin bar magnet.

Fig. 21.

Application of the Law of Inverse Squares.—We should find the problem of calculating what action one magnet has upon another an exceedingly difficult one if we were not allowed to assume that the magnetism acted as if it were concentrated at the ends of the magnet. Let us agree that this assumption may be made, at least with long and thin magnets, and let us consider two such magnets NS and N′S′ (Fig. 21), so placed that the S and S′ poles

[1] Or use a sundial at noon.

are sufficiently distant to make their action negligible. The force of repulsion between N and N′ will depend upon two things :—

(1.) The strength of each of the poles.
(2.) The distance of the poles apart.

The exact law can be best written down in symbols as follows :—

FUNDAMENTAL LAW.

If f and f′ be the magnetic strengths of two poles, and d the distance between them, then the whole force F of mutual repulsion or attraction will be

$$F = \pm \frac{ff'}{d^2},$$

the upper sign being used when there is repulsion and the lower sign when there is attraction.

It is of the very first importance that the reader should grasp the meaning of this fundamental law. We shall give a numerical example of its use.

Example.—Let the strength of one pole be + 8 units and the strength of a second pole be − 20, or, in other words, let one be a N pole of strength 8 and the other a S pole of strength 20. Suppose that the poles are 2 units of distance apart, and that we are required to determine the force of attraction or repulsion. Here

$$F = \frac{(+8) \times (-20)}{2^2} = -\frac{160}{4} = -40,$$

and the force is an attractive one of 40 units.

Application of Fundamental Law.—The above law supplies the key to explain the magnetic curves. Let the student draw a line NS (Fig. 22) representing the long and thin magnet, and consider the position that a small magnet **ns** would assume when placed in the field of the magnet at

the point O. Now the poles of the little magnet would be acted upon by four forces:—

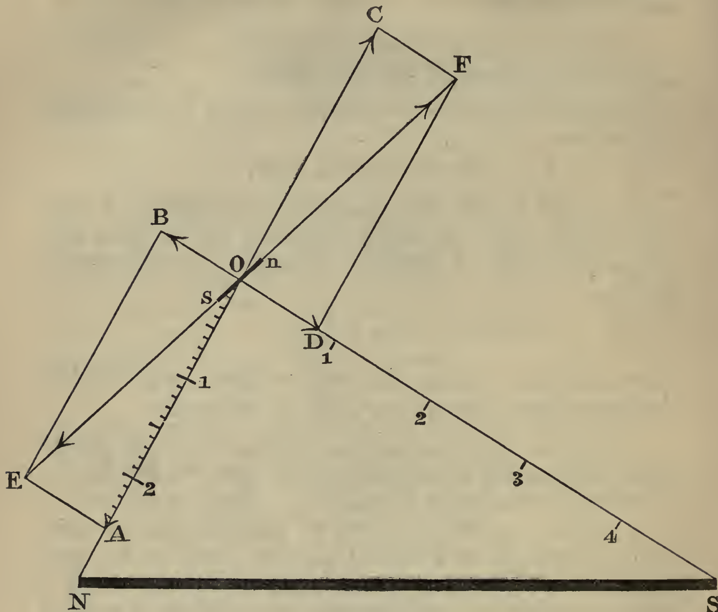


Fig. 22.

OA = The attractive force of N upon s, the south pole of the little magnet.
OB = The repulsive force of S upon s.
OC = The repulsive force of N upon n, the north pole of the little magnet.
OD = The attractive force of S upon n.

To find the lengths of the lines representing these forces we must use our fundamental law. Suppose that the strength of the pole N is + 100 units and that the strength of the pole S is – 100 units, whilst that of n is + 2 and that of s – 2 units. We shall further make the assump-

tions that the little magnet is so small that the distance between its poles need not be considered, and further that ON is 3 and OS 5 units long. The fundamental law then gives :—

$$OA = \frac{+100 \times -2}{3^2} = -\frac{200}{9}.$$

$$OB = \frac{-100 \times -2}{5^2} = +\frac{200}{25}.$$

$$OC = \frac{+100 \times +2}{3^2} = +\frac{200}{9}.$$

$$OD = \frac{-100 \times +2}{5^2} = -\frac{200}{25}.$$

The lengths of OA, OB, OC, and OD are therefore known. It is quite immaterial what lengths we give to these lines providing that the correct ratio is observed. Now

$$\begin{aligned} OA : OB &= \frac{200}{9} : \frac{200}{25}, \\ &= 25 : 9. \end{aligned}$$

Hence OA must be made 25 and OB 9 units long.

Complete the parallelogram AOEB and draw the diagonal OE, which will represent in magnitude and direction the resultant force. In a similar manner we can find OF, which is equal and opposite to OE. The small magnet at O will therefore be in equilibrium, and have no tendency to leave its position. It will, however, set itself along the line OF. *The line OF will be a tangent to the magnetic curve or line of force passing through O.*

Exercises.—Follow out the same method of construction to find the position which a small magnet would assume when placed as follows :—

(1.) Above the middle of NS.

(2.) Vertically over N.

(3.) On a line which is a prolongation of NS.

Experimental Verification.—In the above investigation we have assumed that

(1.) The poles were at the end of the long magnet.
(2.) Its length was great compared with the small magnet.
(3.) No other forces were acting except those between the two magnets.

In practice we must therefore take care to secure approximately the first two conditions. The third it would be difficult to secure, for we cannot very well eliminate the action of the earth. But we may proceed as follows :—

Place the small compass needle at O and turn the drawing board until the compass needle lies along EF. It will then be at rest under the action of the earth alone. Now place the long magnet at NS, when the needle should still point along EF if the theory is correct. Repeat the process at the other positions. What is done here is to make the direction of the little compass needle at each point coincide with the magnetic meridian, in which case the earth's action does not affect the conditions of equilibrium.

27. *Lines of Force.*—The curious curves exhibited by iron filings will prepare the student to understand what is meant by *lines of force.* Lines of force may be regarded as graphical representations of the action of force. A unit of mass or pound may be regarded as falling to the earth very much as if the mass had a string attached to it which an operator at the earth's centre was always pulling with a constant force. Now this mental image of strings as representing the action of terrestrial gravity is capable of advantageous extension.

We may, for instance, suppose that a very great but yet strictly constant number of such strings passes from the earth's centre to points symmetrically disposed along the earth's surface ; these points being likewise very close together, and that the well-known phenomena of weight are due to such strings (see Fig. 23).

Now what will happen on this hypothesis if we go to a surface ten times as far from the earth's centre as is our present abode? Will these strings, or an ideal continuation of them, still represent the action of the earth upon a unit of mass placed at this increased distance from its centre? Let us see whether or not this will be the case. First consider the surface of the earth where we live, and let us suppose that terrestrial gravity acting on unit of mass is really due to a very great but strictly constant number of such strings, each giving the same pull and symmetrically spread over the earth's surface.

Now at the increased distance, ten times farther off from the earth's centre, if the mental image is to hold good, we can only have the same number of strings that we have here. But these strings, or a continuation of them, will now be spread over a surface having a hundred times the area of the earth's surface, so that the number of such strings that will pass through one unit of mass will be a hundred times smaller

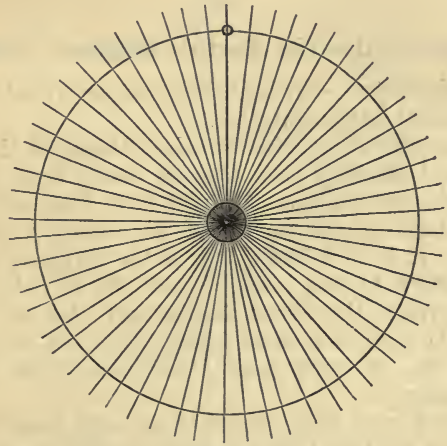


Fig. 23.

at the increased distance. If, therefore, the analogy is still to hold good, the force at this increased distance must as a matter of fact be diminished likewise in this proportion. Now this is precisely what astronomers find to be the case, for they have proved that the force of gravity varies inversely as the square of the distance, so that (as we have already mentioned in Art. 12) the force at this increased distance will be 10^2 or 100 times less than at the earth's surface. It thus appears that at these two distances, and in fine at every distance, the earth's force upon a pound of matter may be regarded as proportional to the number of lines or strings of force which pass through the substance. And it is likewise obvious that when such lines of force are very close together, this denotes a region where the force is very strong, and that when such lines are very far apart this denotes a region where the force is very weak.

In the above instance, if a small stone be dropped towards the earth it will proceed along one of these lines of force and in a straight line.

But in the case of a magnet the lines of force are, as we have seen, curved and not straight, and the force which such a magnet will exert upon an *exceedingly* small compass needle will be directive merely; that is to say, the small compass needle will not be carried bodily along the line of force which passes through it, but merely made to point so that its length will lie along the line, the one pole being as much attracted as the other is repelled.

Lesson XII.—The Earth's Magnetic Action.

28. *Apparatus.*—Sewing needle, magnet, vessel of water, mathematical instruments, etc.

The Earth's Force Directive only.—Magnetise the sewing needle, and carefully place the dry needle upon the water in a horizontal position. It will now float, and may be moved about on the surface of the water by means of a magnet. If it is deflected out of the magnetic meridian, it will return to this meridian, with its N pole pointing north, provided there is no magnet near; *but will show no tendency to move as a whole towards the north or south pole of the earth.* In other words, the action of the earth is *directive* only.

To explain why this should be we must refer to Lesson XI., where we found that a small magnet placed in the field of a large one is under the action of *two equal and opposite forces*, which can only produce rotation. Thus (Fig. 24), suppose that nOs is a compass needle that is displaced from the meridian MR, so as to make an angle a with this meridian; it will be acted upon by the equal and opposite forces called the *terrestrial magnetic couple*, which tend to bring the magnet into the meridian.

Now as we know nothing about the strength of the earth's poles, or the distance of them from the needle, we shall express the force acting on the n pole of strength f by

$$+f\mathrm{H},$$

where H is defined to be *horizontal component of the earth's magnetic force.*

In like manner the force acting on the s pole is

$$-f\mathrm{H}.$$

These, then, are the two forces constituting the terrestrial magnetic couple.

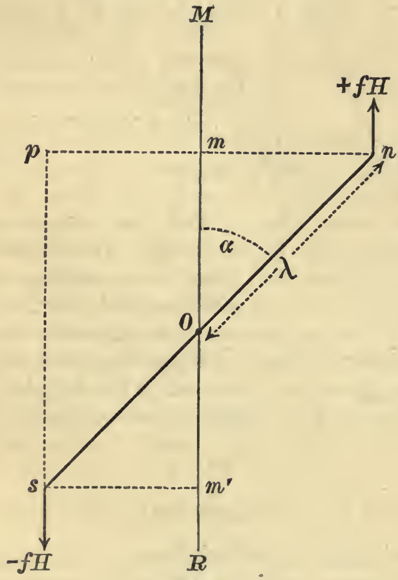


Fig. 24.

The student who is not familiar with trigonometry must now be made acquainted with the meaning of the term **sine**. Draw the triangle ABC (Fig. 25) with a right angle BCA.

Let the angle BAC	. . . . .	$=a$
BC, the side opposite to a	. . .	$=o$
AC ,, adjacent to a	. . .	$=a$
AB, or the hypothenuse	. . .	$=h$

Measure o, a, and h. Then the sine of the angle a is

equal to the ratio of the opposite side o to the hypothenuse h, or, briefly,

$$\sin \alpha = \frac{o}{h}.$$

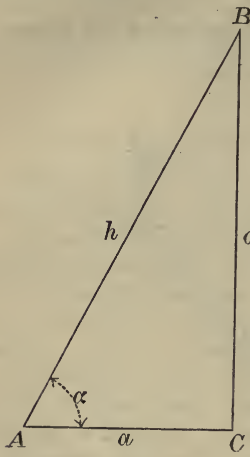


Fig. 25.

Example.—Suppose $o = 8$ and $h = 12$, then $\sin \alpha = \frac{8}{12} = \dot{6}$.

We shall presently have to use two other relations, namely, the cosine and tangent.

$$\text{cosine } \alpha \text{ (abbreviated to } \cos \alpha) = \frac{a}{h},$$

$$\text{tangent } \alpha \text{ (} \quad ,, \quad ,, \quad \tan \alpha) = \frac{o}{a}.$$

For the purpose of finding the angle corresponding to a given sine, cosine, or tangent, mathematical tables must be used (see Appendix D).

Returning now to Fig. 24, if we call λ the half length of the needle, we see that

$$\sin \alpha = \frac{mn}{\lambda},$$

or

$$mn = \lambda \sin \alpha,$$

also

$$m's = \lambda \sin \alpha,$$

and

$$pn = 2mn = 2\lambda \sin \alpha.$$

But pn is the perpendicular distance between the forces constituting the couple. In works on mechanics it is shown that the moment of a couple is found by multiplying the strength of one of the forces by the perpendicular distance between them. Hence the moment F tending to bring the needle into the meridian is

$$F = fH \times 2\lambda \sin \alpha.$$

The above expression (equivalent to $2\lambda f H \sin \alpha$) may

be simplified if we introduce the definition of the moment of a magnet.

Definition.—The moment of a magnet is the product of the strength of one of its poles multiplied by the distance between them.

Call the moment of the magnet μ, then

$$\mu = 2\lambda f,$$

and

$$F = \mu H \sin \alpha,$$

or the moment tending to bring the compass needle into the meridian is equal to the *united product of the magnetic moment of the needle, the horizontal component of the earth's magnetism, and the sine of the deviation from the meridian.* The student should fix this formula in his memory.

Exercises.—When $\lambda = 4$ units, $f = 1$ unit, $H = 6$ units, (1) find the turning moment when α is 30° and also when α is 45°. (2.) Find the moment of a magnet whose half length or λ is 6 while the strength of one of its poles is 5. (3.) Find the strength of the earth's magnetism where the moment required to keep a needle of moment 5 deflected 30° is 50 units.

Lesson XIII.—Determination of the Dip.

29. *Apparatus.*—A dip circle and needle, or materials for making these. Fig. 26 shows a form of dip circle especially designed for the work of this lesson. Fig. 26*a* is a simpler form, such as could be made by the student.

Materials for making Dip Circle.—(1.) Block of wood 10 cm. square and 2·5 cm. thick. (2.) Four corks. (3.) Glass rod. (4.) Strips of looking-glass. (5.) Sewing needle. (6.) Cardboard.

Operations.—(1.) Make the stand and uprights of dimensions and materials shown (Fig. 26*a*). The supports for the needle are seen at *ab* and *cd*. The ends at *b* and *c* are made V-shaped by heating the glass in the blowpipe and then touching it with the end of a heated file. (2.) Divide a card into degrees and number it in four quadrants in the order 0°, 90°, 0°, 90°. Cut out two sectors *ss'* stretching from 60°

to 60°, and cement two pieces of looking-glass across these openings (3.) Make the needle. A satisfactory needle can be made by any one having the necessary patience in the following manner: (*a*.) Take a piece of crinoline steel, cut into shape as exactly as possible by means of shears. (*b*.) Drill a central hole just sufficiently large to admit a sewing needle. The strip of steel supported by the sewing needle as a horizontal axis should remain balanced in any position. If this is not so the balance must be made perfect by filing the ends of

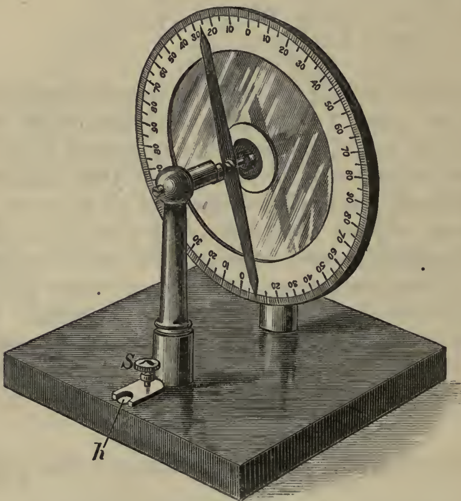


Fig. 26.—Dip Circle.

the strip of steel. (*c*.) Wrap iron wire round the strip of steel and heat to bright redness in the blowpipe flame. Plunge vertically into cold water. If the blowpipe flame be not sufficiently large to heat the whole of the strip of steel at once, first one end and then the other must be hardened. (4.) Cut out two wads of cardboard by means of a cork borer. Place one on either side of the strip of steel and thrust a sewing needle, that is to serve as an axis, through the centre of one wad, then through the hole in the strip of steel, and finally through the centre of the other wad. Secure the wads to the steel by balsam cement. The needle should now be put away until the cement sets. Test whether the steel remains balanced, and if not, a final adjustment must be made by grinding on a stone. (5.) Magnetise the needle by

the method of *divided touch.* On the base of the dip circle a hole h is drilled sufficiently large to admit the pivot of the dip needle and the fixing wad. We must fix, for the purpose of magnetisation, the dip needle flat to the wooden base (with one of its pivots inserted in the hole) by means of a strip of brass provided with a screw S (Fig. 26). We now take a magnet in each hand and place the opposite poles

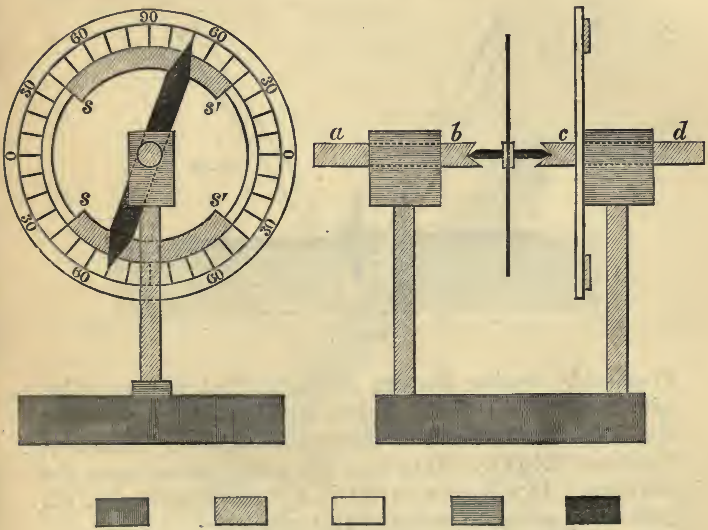


Fig. 26*a*.

near the centre of the needle (Fig. 27), and draw the magnet from the middle to the ends of the needle about twenty times. The needle is then turned over and the process repeated on the other side.

Theory of the Dip Needle.—When discussing the earth's magnetic action in Lesson XII., we only considered that part of the earth's magnetic force that tends to bring the compass needle into the magnetic meridian when displaced therefrom. Nothing was said about any tendency of the

needle to tilt due to any vertical force, for such force would be counteracted by the resistance of the supporting cap of the compass needle. By mounting the magnet so as to allow any vertical force to have an evident action, as we do in the dip needle, we may study this vertical force.

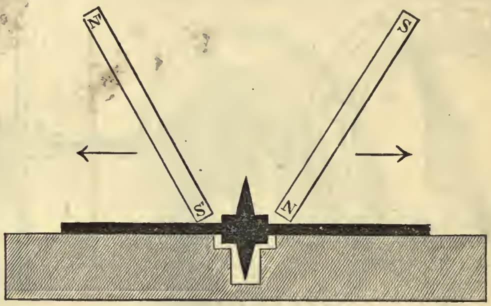


Fig. 27.

Further, by setting the dip needle so that it may swing with its plane in the magnetic meridian, we may observe the simultaneous action of the horizontal force. Consider, therefore, SN (Fig. 28) to be a dip needle swinging in the meridian. It will come to rest in a position inclined to the horizontal, owing to action of two couples—

(1.) The horizontal magnetic terrestrial couple $-\mathrm{H}f$ and $+\mathrm{H}'f$.

(2.) The vertical magnetic terrestrial couple $-\mathrm{V}f$ and $+\mathrm{V}'f$, and its position will be such that $-\mathrm{T}f$ and $+\mathrm{T}'f$, the resultant couple-forces, have no moment, but act merely as two opposite pulls upon the needle.

The resultant of H and V or of H′ and V′ is called the *total magnetic force*, and the angle TOB that the needle makes with the horizontal is called the *inclination or dip of the needle.* Let us call this angle δ.

Looking at the figure and remembering that

$$\text{tangent of an angle} = \frac{\text{side opposite to angle}}{\text{side adjacent to angle}},$$

we find

$$\tan\delta = \frac{Vf}{Hf} = \frac{V}{H},$$

or

$$V = H \tan\delta.$$

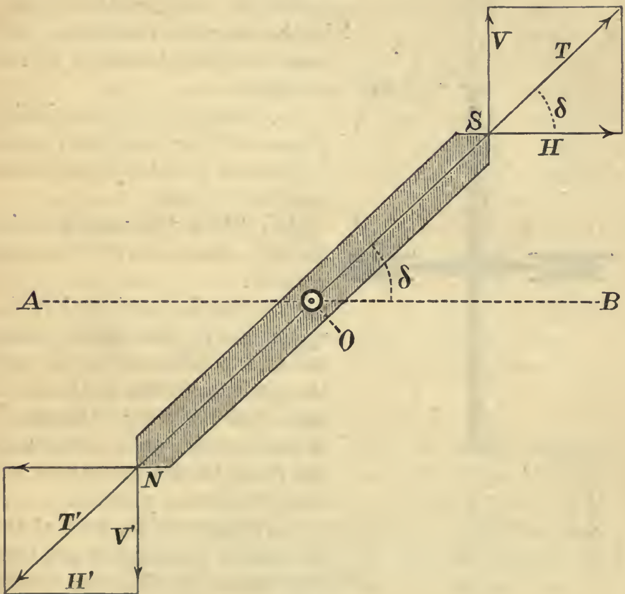


Fig. 28.

This is a very important relation, for if we know two of the quantities the third can be found.

Again

$$\cos\delta = \frac{Hf}{Tf} = \frac{H}{T},$$

or

$$T = \frac{H}{\cos\delta}.$$

Exercises.—(1.) The horizontal magnetic component was ·2 unit and the dip was 60°. Find the vertical magnetic component. (2.) Find the total magnetic force from the same data.

Fig. 29.

Method of Conducting a Dip Observation.—Our first object is to set the needle with its plane in the magnetic meridian. The most convenient method will be as follows :—

(*a.*) Load the dip needle by means of the weighted cork, into which the sharp end of the needle is thrust.

(*b.*) Place the needle on its pivots, when it will become vertical.

(*c.*) Set the card so that the upper end of the needle points to 90°. Whilst setting the card the position of the eye must be such that the end of the needle covers its reflection in the mirror glass, for we then avoid the error known as *parallax*.

(*d.*) Remove the load at the bottom of the magnet and turn the stand of the dip needle until the needle is vertical. It is clear that we have now the needle with its plane at right angles to the meridian, for if we consider Fig. 29, where we see a dip needle in this position, we shall perceive that the horizontal couple tends only to raise one end of the pivot of the magnet. The vertical couple is thus left free to bring the magnet into a vertical position.

(*e.*) Mark the position that the base occupies when the needle is vertical by running a pencil line round the base, and then turn it through 90°. The needle will now be in the desired position with its plane in the magnetic meridian.

The needle and dip circles are liable to several errors.

Sources of Error.—With regard to the needle there may be (1.) a want of symmetry in mass, that is to say, the centre of gravity of the needle may not coincide with its axis of motion. (2.) A want of symmetry in magnetism, that is to say, the magnetic axis may not be coincident with the axis of figure. (3.) There may be friction or adhesion of the axles as they rest upon their supports. In the next place, with regard to the instrument, the axis of rotation of the needle may not pass through the centre of the vertical circle, and the circle itself may not be properly set.

The error due to friction must be made as little as possible by keeping the pivots and bearings clean. To eliminate the other errors we must follow the method of observation described below :—

Method of Observation for Determining the Dip.—(1.) Presuming that the instrument has been set with its plane in the magnetic meridian, and that the pivots and bearings are clean, let us suppose that the *face* of the instrument (that is to say, the side bearing the graduation marks) is towards the magnetic *east*. Further, let us suppose that one side of the needle, the *face* (distinguished by a scratch or letters), is towards the face of the instrument. Read both ends of the needle, estimating to a tenth of a degree. (2.) Now turn the instrument to magnetic west, and again take the readings. (3.) Then *reverse* the needle and repeat them, and then, keeping the needle reversed, turn the face to magnetic *east* and repeat the first set of observations once more, with the difference that the *back* of the needle is now turned to the face of the instrument.

Of the two extremities of the needle, which are marked say, α and β, let us suppose that α dips. We have thus made in all eight observations, as follows :—

			Upper Extremity.	Lower Extremity.
Face of instrument east,		Face of needle to face of instrument . .	A_α	A'_α
,, ,,	west	,, ,,	B_α	B'_α
,, ,,	,,	Back of needle to face	C_α	C'_α
,, ,,	east	,, ,,	D_α	D'_α

(4.) We must now reverse the polarity of the needle by the method of "divided touch," so as to make β dip. (5.) We may therefore suppose the needle to be saturated with magnetism, the end β dipping. Having cleaned its axles with cork, let us now proceed to make with it a series of eight observations, precisely analogous to these already described. Call these

$$A_\beta, A'_\beta;\ B_\beta, B'_\beta;\ C_\beta, C'_\beta;\ D_\beta, D'_\beta.$$

The observation is now complete, and the mean of the sixteen readings will give us the true dip.

Theory of the Method of Observation.—The various processes are rendered necessary by the possibly faulty construction of the needle and the imperfect placing of the vertical circle.

A needle, assuming that its axle is truly cylindrical, may yet be imperfect in three ways :—

(α) Its centre of mass may not coincide with its centre of motion as regards the length of the needle.

(β) Its centre of mass may not coincide with its centre of motion as regards the breadth of the needle.

(γ) Its magnetic axis may not coincide with its axis of figure.

Exercise.—Draw diagrams representing these several

faults; cut out models in thin cardboard of needles with these faults. The error β may be represented by a strip of cardboard gummed to one side of the cardboard needle.

Again, the axis of motion of the needle may not pass through the centre of the graduated circle. This last error, or that caused by eccentricity, is overcome by reading both ends of the needle.

Exercise.—Draw a graduated circle and a radius ON (see Fig. 30) at an angle of say 45° with OO, also an eccen-

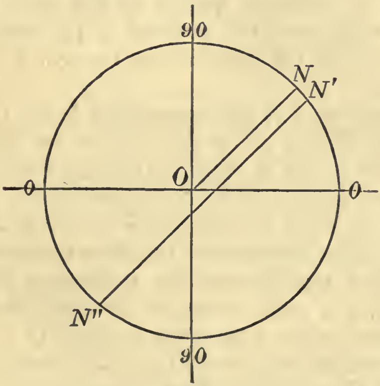


Fig. 30.

tric diameter N′N″ parallel to ON. Now N′N″ represents the needle, and the student should verify that the mean of the readings at N′ and N″ is equal to the reading at N.

When the needle is reversed in its bearings the action of the needle errors (β) and (γ) will be likewise reversed. The student may assure himself of this statement by making the model needles transparent by steeping them in paraffin, having previously denoted the magnetic axis by an ink line and the centre of gravity by a dot of ink. It will

at once be seen that if the action of either error is (say) to increase the dip when the face of the needle is towards the observer, it will act so as to diminish the dip when the needle is reversed.

When the face of the circle is turned round through 180° the extremities of the needle are brought into different quadrants of the vertical circle. If, therefore, the points (90°) have been erroneously set, so as to make the needle read too low in the previous position, it will now read too high, and thus by taking a mean of the two the error caused by an erroneous setting of the circle is avoided. Another advantage of this reversal of the vertical circle is that new points of the steel axle are brought in contact with the bearings.

The only error left uncompensated is (a), for it will be noticed that during all these changes its position with respect to the axis of motion remains unreversed.

This error is got rid of by reversing the poles of the needle. For if, when the first series was made, the centre of mass should have happened to be below the axis of motion, thus causing a moment tending to increase the dip, after the reversal, the same centre of mass will be above the axis and thus cause a moment tending to diminish the dip. The student may render this point obvious to himself by means of the models steeped in paraffin.

Having thus described the reason for the various steps of the process, it only remains to state that in the determination of the position of verticality it is obviously unnecessary to reverse the poles of the needle, inasmuch as any displacement of the centre of mass of the needle with regard to its length could have no effect in altering its verticality. It is only when the needle assumes a non-vertical position that this can be influenced by the error in question.

Example.—

Pole α Dipping.			Pole β Dipping.		
A_α	A'_α	mean	A_β	A'_β	mean
67·3	67·3		67·4	67·4	
		67°·3			67°·4
B_α	B'_α		B_β	B'_β	
68·2	68		67·3	67·4	
		68°·1			67°·35
C_α	C'_α		C_β	C'_β	
67·8	67·6		67·9	67·8	
		67°·7			67°·85
D_α	D'_α		D_β	D'_β	
67·3	67·3		67·1	67·2	
		67°·3			67°·15
Mean of means .		67°·60	Mean of means .		67°·44
Mean of all the observations, 67°·52.					

30. *Action of one Magnet on Another.*—We have shown that the couple urging a magnetic needle back to its position of rest will be

$$2\lambda f'H \sin \alpha \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where

λ = half length of needle.
f' = strength of one of its poles.
H = horizontal strength of earth's magnetism.
α = deviation of compass from meridian.

Let us now proceed to study the action of a magnet upon a needle. Suppose that the needle nOs is kept deflected by a powerful horizontally-fixed permanent magnet NS (Fig. 31), placed with its axis in a line that is perpendicular to the magnetic meridian, and that passes through the centre of suspension of the magnetic needle. Let $\pm f$ be the strength of the poles of the fixed magnet, $2l$ the distance between its poles, and d the distance of its

centre from the centre of the needle. Also let $\pm f'$ be the strength of the poles of the needle.

If we suppose λ to be very small compared to the distance d, and if the angle a is not great, then the dis-

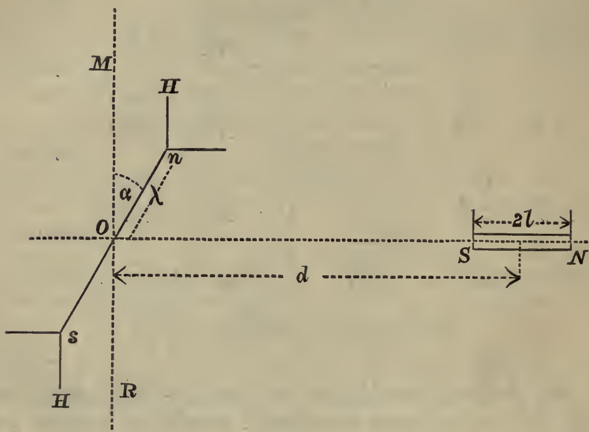


Fig. 31.

tance of the pole S from n or s will be approximately represented by $d - l$, while that of the pole N from n or s will be approximately represented by $d + l$.

We thus find (assuming the law of force to be that of the inverse square)

$$\text{Attraction of S upon } n = \frac{-ff'}{(d-l)^2}.$$

$$\text{Repulsion of N upon } n = \frac{+ff'}{(d+l)^2}.$$

Hence total attractive action upon n

$$= ff' \left\{ \frac{1}{(d+l)^2} - \frac{1}{(d-l)^2} \right\},$$

$$= \frac{-4ff'ld}{(d^2-l^2)^2}.$$

In like manner the total repulsive action upon s

$$= \frac{+4ff'ld}{(d^2 - l^2)^2}.$$

Bearing in mind that this force makes approximately an angle $(90 - \alpha)$ with the length of the needle, we thus see that the needle is acted upon by a couple whose moment is

$$\frac{8ff'l\lambda d \cos \alpha}{(d^2 - l^2)^2}.$$

Now this moment must (since there is equilibrium) be equal to that of the earth's magnetic couple; hence

$$\frac{8ff'l\lambda d \cos \alpha}{(d^2 - l^2)^2} = 2f'\lambda \mathrm{H} \sin \alpha ;$$

or

$$\frac{2fl}{\mathrm{H}} = \frac{(d^2 - l^2)^2}{2d} \tan \alpha.$$

It will be seen that $2fl$ is the strength of the one pole of the permanent magnet multiplied by the distance between the two poles; this is called the *moment of the magnet.* If we designate this moment by M we have

$$\frac{\mathrm{M}}{\mathrm{H}} = \frac{(d^2 - l^2)^2}{2d} \tan \alpha \quad . \quad . \quad . \quad (\mathrm{I}_b)$$

and if d be very great compared with l this will become

$$\frac{\mathrm{M}}{\mathrm{H}} = \frac{d^3}{2} \tan \alpha \quad . \quad . \quad . \quad (\mathrm{I}_a)$$

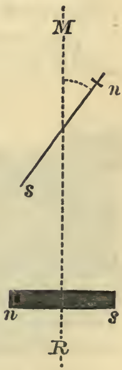


Fig. 32.

In a similar manner the relation between M and H can be ascertained when the magnet is placed *broadside on*, as in Fig. 32. These two positions we shall call the A and B **Tangent Positions of Gauss.**

In the following table are given the first and second approximations to the value of $\frac{\mathrm{M}}{\mathrm{H}}$ for the two cases A and B.

TABLE D.

FORMULÆ FOR THE TANGENT POSITIONS A AND B OF GAUSS.

Position.	1st Approximation (*a*).	2d Approximation (*b*).
A	$\frac{M}{H}=\frac{d^3 \tan \alpha}{2}$	$\frac{M}{H}=\frac{(d^2-l^2)^2 \tan \alpha}{2d}$
B	$\frac{M}{H}=d^3 \tan \alpha$	$\frac{M}{H}=(d^2+l^2)^{\frac{3}{2}} \tan \alpha$

Note.—It is very tedious to use formulæ like the above unless logarithms are employed. *Four-place* logarithms are sufficient, and the student should at once be made acquainted with their method of application, which presents no difficulties (see Appendix D). It may be noticed that formula A(*b*) for purposes of calculation may be written

$$\frac{(d-l)^2(d+l)^2 \tan \alpha}{2d}.$$

LESSON XIV.—Action of one Magnet on another.

31. *Exercise.*—To prove the formulæ of the preceding paragraphs experimentally.

Apparatus.—A compass box with a small magnetic needle (Fig. 33) pivoted at the centre of a card graduated

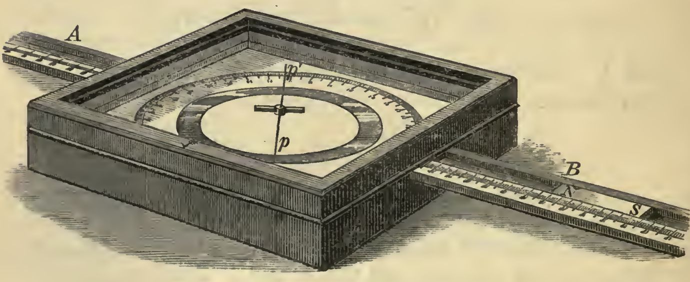


FIG. 33.—DEFLECTION MAGNETOMETER.

into degrees. The needle has a pointer pp' of brass wire placed at right angles to the magnetic needle. To avoid

parallax in reading the position of the pointer the bottom of the compass box is provided with a mirror, which is indicated by the shaded ring. The compass box is provided with two arms, A and B, with central grooves formed on one side by a boxwood millimètre scale. A short but powerfully magnetised bar magnet NS will likewise be required.

Method.—Arrange the apparatus for the A position of Gauss. See that both pointers are at zero. Place the bar magnet NS on the east limb of the instrument, with its N

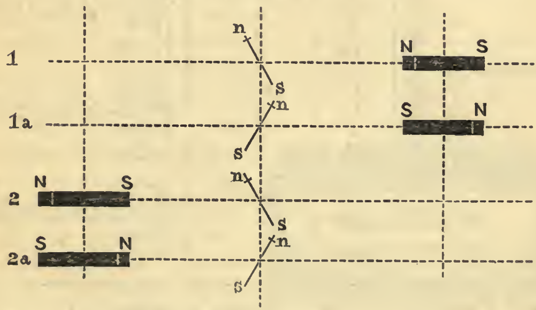


Fig. 34.

pole west, and note the deflection produced by means of the pointers. Note at the same time the exact distance between the centres of the two magnets. Then turn the magnet *end for end*, so that while its centre preserves the same position its south pole is now nearest the needle, and again read the deflected position of the pointers. Next take the magnet to the other limb of the instrument, leaving its distance from the centre of the needle the same as before, and obtain a series of deflections similar to those already described. Fig. 34 shows the various positions. Take the mean of the deflections in order to obtain the angle a. Lastly, repeat the observations with different

distances, and then calculate the value of $\frac{M}{H}$ with the aid of the preceding formulæ.

Repeat the experiment for the B position of Gauss.

Example.—

A POSITION.

	Position.	Distance of Magnet from Compass Box.	Deflection (α).
Experiment I.—			
	1	20 cm.	11°·25
	1*a*	,,	11°·0 —Mean, 11°·125
	2	,,	11°·0
	2*a*	,,	11°·25
Experiment II.—			
	1	10 cm.	30°·00
	1*a*	,,	30°·00—Mean, 30°·19
	2	,,	30°·50
	2*a*	,,	30°·25
Experiment III.—			
	1	5 cm.	49°·00
	1*a*	,,	53°·00—Mean, 51°·06
	2	,,	53°·00
	2*a*	,,	49°·25
Length of magnet = 10·5 cm. Diameter of compass box = 18·0 cm. Length of compass needle = 28·5 mm.			

The difference between the values in Experiment III. would seem to indicate that the magnet was too near the compass box, hence we shall reject the result.

		Exp. I.	Exp. II.
Using Formula (A_a)	$\frac{M}{H}$ =	3949·4	4148·4
,, (A_b)	$\frac{M}{H}$ =	3767·0	3768·7

LESSON XV.—Study of a Vibrating Magnet.

32. *Apparatus.*—The magnet intended to be put in

vibration should be suspended in a box (Fig. 35) by means of a few fibres of unspun silk. The silk thread is supported by a small hook *h* held by a boxwood cap *c* that fits over the top of a glass tube *t*. The latter is fixed in a hole in the top of the box by the help of the boxwood mounting *c′*. At the top of the box is a narrow glass window *w*. A strip of mirror glass is fixed to the bottom of the box, and has an index line *ii′* across its middle. A stirrup of thin copper *s* is used to support the magnet, at one end of which a piece of paper with an index mark *m* is gummed. The front and back of the box are sliding doors of glass.

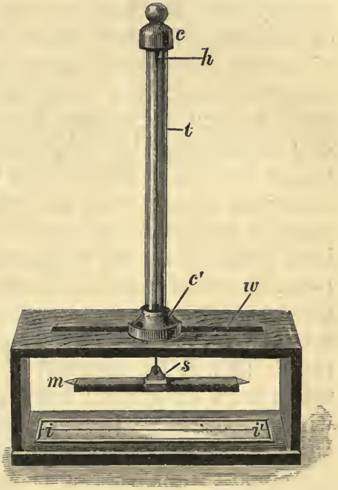


Fig. 35.—Vibration Magnetometer.

The apparatus may be readily constructed from one of the postal boxes, if corks be used instead of boxwood, and only one sliding door of glass employed.

Law of a Vibrating Magnet.—We proceed to give a formula of very great value in magnetic measurements.

$$t=\pi\sqrt{\frac{\mathrm{I}}{\mathrm{MH}}}$$

where *t* is the *time in seconds* required for the magnet to make one oscillation (that is to say, a single swing), π is the ratio of the circumference of a circle to its diameter, or 3·1416 nearly, M is the *moment of the magnet*, H is the *horizontal component* of the earth's magnetic force, and I is

the *moment of inertia* of the magnet. The meaning of this latter term will require explanation.

Definition of Moment of Inertia.—When a solid body is made to vibrate or rotate (let us say rotate, for this is simpler) it is clear that all the particles of the body are not moving with the same velocity. For those near the axis of rotation will move comparatively slowly, while those at a distance from it will move comparatively fast. Now the energy or work that must be bestowed upon the body in order to start its rotation depends upon the absolute velocity communicated to these various particles. Thus, for instance, suppose that we have a thin steel wire, of which the mass may be neglected, and which is made to rotate horizontally around an axis at its centre, and furthermore let both arms be loaded with equal masses of lead placed at equal distances from the centre. Then it will require four times as much energy to make the system rotate once in a second, if the lead be placed two décimètres from the centre, as will be necessary if the lead be only one décimètre from the centre; because in the former case the lead will be constrained to move twice as fast as in the latter—and this means a fourfold energy.

Suppose now that a complicated system, such as a heavy top, is made to rotate say once in a second. There is in any such system a certain distance from the axis such that if we imagine the whole mass of the system to be concentrated at that distance, then will the energy necessary to rotate this *imaginary* system once in a second be the same as that necessary to rotate the *actual* system at the same rate. This point or distance from the axis at which we have imagined the mass to be concentrated is called the *centre of gyration*, and the perpendicular distance between it and the axis the *radius of gyration*. Again, the whole mass multiplied by the square of the radius of gyration is called the *moment of inertia*, or I; and if ω denote the angular velocity of the body, or velocity at distance

unity from the axis, then will the whole energy of rotation be denoted by the expression $\frac{1}{2}\omega^2 I$; that is to say, by one half the square of the angular velocity multiplied by the moment of inertia.

Calculation of Moments of Inertia.—The following rules will be useful:—Rectangular parallelopiped, axis through centre and perpendicular to the side contained by a and b—

$$I = W\frac{a^2+b^2}{12}.$$

Right cylinder, of length l and radius of section $= r$, axis through centre perpendicular to axis of cylinder—

$$I = W\left(\frac{l^2}{12}+\frac{r^2}{4}\right),$$

where W is the mass of the body.

Application of Formula.—We have

$$t = \pi\sqrt{\frac{I}{MH}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

hence

$$t^2 = \frac{\pi^2 I}{MH} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

from which

$$MH = \frac{\pi^2 I}{t^2} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or the product MH varies inversely as the square of the time of oscillation.

Application 1st.—If we carry the same magnet to different parts of the earth, taking care that its magnetic moment remains the same by keeping the magnet free from concussions and great changes of temperature, then we can ascertain the relative value of H at any two places. Thus at a certain place we may have

$$MH' = \frac{\pi^2 I}{t'^2} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where t' is the time of oscillation.

Hence from (3) and (4)

$$\frac{H}{H'}=\frac{t'^2}{t^2} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Exercise.—A magnet in London made 135 oscillations in 50 seconds, and when in Edinburgh made 127 oscillations in the same time. What is the relative value of the horizontal component at the two places?

Application 2nd.—Magnets of the same shape and weight have the same moment of inertia, hence, if they are vibrated at the *same place*, we may compare their magnetic moments. Thus with a magnet of moment M′ we may have

$$M'H=\frac{\pi^2 I}{t'^2} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

hence, from (3) and (6),

$$\frac{M}{M'}=\frac{t'^2}{t^2} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Exercise.—Two magnets of equal moments of inertia gave times of vibration 1·23 and 3·69 seconds. Compare their magnetic moments.

Application 3rd.—The magnet under vibration may be of an irregular form, of which it would be difficult to calculate the moment of inertia. If we attach to the vibrating magnet a body of definite form made of non-magnetic material, we may then ascertain experimentally the moment of inertia of the magnet, for

$$MH=\frac{\pi^2(I+I')}{t'^2} \quad . \quad . \quad . \quad . \quad (8)$$

where I′ is the calculated moment of inertia of the non-magnetic body, and t' the time of vibration of the combined system.

Hence, from (3) and (8),

$$\frac{I}{I+I'}=\frac{t^2}{t'^2} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

therefore
$$\frac{\mathrm{I}}{\mathrm{I}'}=\frac{t^2}{t'^2-t^2}$$

or
$$\mathrm{I}=\mathrm{I}'\frac{t^2}{t'^2-t^2} \quad . \quad . \quad . \quad . \quad (10)$$

Exercise.—A magnet gave $t=4$, and when a bar of brass was added to it $t'=8$. Find the moment of inertia of the magnet, supposing that the moment of inertia of the brass bar is 50.

Experimental Work.

Exercise I.—Compare the magnetic moments of two magnets A and B of the same weight, size, and shape.

Method.—(*a.*) Place the vibration box so that the line joining the index threads is in the magnetic meridian. The box should likewise be placed at a convenient height for observation by supporting it on a wooden block or stool. (*b.*) Put the brass bar in the stirrup and allow it to come to rest. If it does not come to rest in the magnetic meridian, this shows that there is torsion in the supporting thread. Turn then the head C that supports the thread round until the bar lies in the meridian. The thread will now be free from torsion. (*c.*) Replace the brass bar by the magnet, having previously gummed a strip of paper at one of its ends; steady the magnet, and, when nearly at rest, cause it to be set into vibration by approaching another magnet. (*d.*) Proceed to find the time of vibration of the magnet. With his head about two feet above the vibration box, let one observer notice when the middle of the magnet crosses the index line, and let him sharply tap on the table; a second observer should meanwhile be ready to note down as accurately as he is able the time at which the signal is given. Call the time of the first signal the time of the 0th passage. Let the first observer continue to count the number of the passages until the 100th is

reached, when he should again give a sharp tap as a signal to the second observer. (*e.*) Subtract the time of the 0th passage from the time of the 100th, and divide the result by 100 in order to obtain the time of a single oscillation. (*f.*) Repeat the process with the magnet B, then apply the formula $\frac{M}{M'} = \frac{t'^2}{t^2}$.

Example.—

Time of Vibration of A—

	h.	m.	s.
Time of 0th passage	1	14	10
,, 100th ,,	1	27	19
Time of 100 oscillations		13	9
		60	
Therefore time of 1 ,,	100)789		
	7·89 seconds.		

Time of Vibration of B . . . . 8·00 ,,

$$\frac{\text{Moment of A}}{\text{Moment of B}} = \frac{8^2}{(7{\cdot}89)^2} = 1{\cdot}03 \text{ nearly.}$$

Exercise II.—To compare the strength of field of the earth with the strength of field produced by placing a long magnet above the vibration box.

Method.—(*a.*) Find the time of oscillation of the suspended magnet as before. (*b.*) Place the long magnet with its long axis in the meridian, and with its south pole to the north, and again determine the time of oscillation. (*c.*) Apply the formula $\frac{H}{H'} = \frac{t'^2}{t^2}$.

Exercise III.—To determine the moment of inertia of a magnet by experiment and calculation.

Method.—(*a.*) Find the time of oscillation of the magnet by itself, and then with a brass bar fastened to it by silk thread. (*b.*) Apply the formula $I = I' \frac{t^2}{t'^2 - t^2}$.

Lesson XVI.—Determination of H and M.

33. *Apparatus.*—The vibration box of the previous lesson and the deflection apparatus of Lesson XIV.

Theory of Method.—Let us write formula (3), page 95, in a simplified form, so

$$MH = A \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where A stands for the right-hand member of the equation. Refer now to page 89, where we obtained a formula

$$\frac{M}{H} = B \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where B is the right-hand member of the expression there given. From (11) and (12) we find, by multiplication,

$$M^2 = AB,$$

or

$$M = \sqrt{AB} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and by division

$$H^2 = \frac{A}{B}$$

or

$$H = \sqrt{\frac{A}{B}} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Formulæ (13) and (14) thus enable us to find simultaneously the moment of a magnet and the horizontal component of the earth.

Exercise.—A = 8, B = 2. Find M and H.

Practice of Method.—This will be sufficiently clear from the following example :—

I.—Deflection Observation.—

Position of Magnet.	Deflection.	
1	47·25	Mean 46·81 = α.
2	47	
3	47	
4	46	

Distance from centre of magnet to centre of deflection needle, 20·3 cm. $= d$. Half length of magnet, 5·1 cm. $= l$.

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan \alpha,$$

$$=\frac{(d+l)^2\,(d-l)^2}{2d}\tan\alpha,$$

$$=\frac{(25{\cdot}4)^2\,(15{\cdot}2)^2}{40{\cdot}6}\tan 46°49',$$

$$=3911.$$

II.—Vibration Observation.

$$a=10{\cdot}2\text{ cm.},\ b=1{\cdot}4\text{ cm.},\ t=7{\cdot}89\text{ seconds.}$$

$$\mathrm{I}=\mathrm{W}\,\frac{a^2+b^2}{12}=68{\cdot}6\frac{(10{\cdot}2)^2+(1{\cdot}4)^2}{12}=6{\cdot}06\text{ nearly.}$$

$$\mathrm{MH}=\frac{\pi^2(6{\cdot}06)}{(7{\cdot}89)^2}={\cdot}9610.$$

Value of H.—

$$\mathrm{H}=\left(\frac{{\cdot}9610}{3911}\right)^{\frac{1}{2}}={\cdot}157.$$

Value of M.—

$$\mathrm{M}=({\cdot}9610\times 3911)^{\frac{1}{2}}=613{\cdot}1.$$

Since all the measurements have been made in *centimètres*, *grammes*, and *seconds*, the above values are in accordance with the C.G.S. system of units.

34. By the preceding method we can find in any particular system of units the moment of a magnet. Once possessed of a magnet of known moment, the comparison of this magnet with any other may be made by balancing one magnet against the other. A convenient apparatus for the purpose we shall call a **Comparison Magnetometer.**

Lesson XVII.—Use of a Comparison Magnetometer.

35. *Apparatus.*—A comparison magnetometer of the following construction :—A short hollow cylindrical magnetic needle *ns* (Fig. 36) is suspended by a fibre of silk within a box similar to the vibration box. Attached to the needle is a pointer *pp′* of glass or aluminium or thin brass wire, weighted at *p′*, whose movement is observed through the window *w*. The pointer swings above a short scale *a*

attached to a strip of looking glass, and the extent of its swing is limited by two stops t and t'. On either side of the box are two arms, A and B, provided with grooves

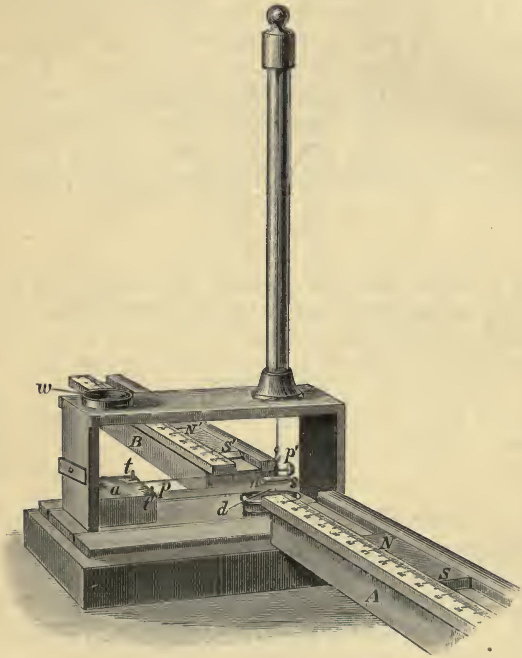


Fig. 36.—The Comparison Magnetometer.

and millimètre scales. These scales are fixed nearly at the same height as *ns*, and on them the magnets under comparison, NS and N′S′, are placed. To assist in bringing the needle to rest a wire *d* passes from its centre and dips in a vessel of water placed at the bottom of the box.

A magnet of known moment will be required for use

with the instrument, and other magnets and pieces of steel for experimental purposes.

Method of Using the Instrument.—Place the instrument on a steady table or stone slab, and turn it until, on looking through the glass-covered hole w in the roof of the box, the end of the pointer (when covering its image in the looking glass) points to zero of the scale a. Now place on the scales the magnets under comparison, NS and N′S′, with their like poles opposing. Then by moving one of the magnets the index can be brought to zero. If D be the distance of the centre of one magnet from the needle, then

$$\frac{M}{H}=\frac{D^3 \tan \alpha}{2},$$

where α is the deflection which one magnet alone will produce; but since the magnet is opposed by the second of moment M′ at distance d, then

$$\frac{M'}{H}=\frac{d^3 \tan \alpha}{2},$$

or

$$\frac{M}{M'}=\frac{D^3}{d^3} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

or the moments of the magnets are directly as the cube of the distances of the centres of the magnets from the needle. As it is a little difficult to obtain the exact distances D and d, it is better to proceed by what is called a *difference method*. Obtain a balance at new distances D′ and d', then

$$\frac{M}{M'}=\frac{D'^3}{d'^3} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From (1)

$$\sqrt[3]{\frac{M}{M'}}=\frac{D}{d}.$$

From (2)

$$\sqrt[3]{\frac{M}{M'}}=\frac{D'}{d'};$$

hence

$$\sqrt[3]{\frac{M}{M'}}=\frac{D-D'}{d-d'},$$

or

$$\frac{M}{M'}=\frac{(D-D')^3}{(d-d')^3} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

that is to say that we only require to note the distance each magnet has been moved from the first balancing position to the second.

By considering M′ as of unit moment and making $d-d'=10$, the formula simplifies to

$$M=\frac{(D-D')^3}{1000} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The above formulæ give only a first approximation. To obtain more correct results a more complicated formula would be necessary. They give, however, all the necessary accuracy for comparing the moments of magnets that have been magnetised in different ways and then subjected to concussion, change of temperature, etc., as in the examples that will now be described.

Examples of the Use of the Comparison Magnetometer.

I. Comparison of two Magnets A and B of equal length.

A on Left.		B on Right.
A at 304	balanced	B at 300
A at 202·5	,,	B at 200

$$\frac{\text{moment of A}}{\text{moment of B}}=\left(\frac{304-202{\cdot}5}{300-200}\right)^3=\frac{101{\cdot}5^3}{100^3}=1{\cdot}045.$$

II. Study of Magnetisation.—(*a.*) A strip of steel was magnetised by the method of *single touch* and balanced against a standard magnet. The latter was kept at 435 on the scale. The effect of the successive strokes that the steel had been submitted to is seen below.

After 1st stroke	Balanced at	115	
,, 2d ,,	,,	150	
,, 3d ,,	,,	160	
,, 4th ,,	,,	162	
,, 5th ,,	,,	164	
,, 10th ,,	,,	177	Magnetisation unstable.
,, 15th ,,	,,	167	
,, 20th ,,	,,	170	
,, 30th ,,	,,	177	

(*b.*) The effect of stroking with copper bar.

Before stroking with copper	182
After 1st stroke	175
,, 2d ,,	170

(*c.*) The same steel strip made as hard as glass and magnetised by single touch.

Strokes.	Readings.	Strokes.	Readings.	
1	148	5	170	
2	159	10	167	Unstable.
3	163	15	175	
4	167	20	168	

(*d.*) A weight was allowed to fall from a definite height on to the strip of magnetised steel.

Initial reading	168
Weight dropped once	160
,, ,, twice	155
,, ,, three times	strip broken.

(*e.*) Study of magnetisation by *divided touch.* Standard at 435.

Strokes.	Readings.	Strokes.	Readings.
1	180	20	255
2	210	30	261
3	222	40	265
4	230	50	266
5	238	60	268
10	250	70	270
15	252	100	275

(*f.*) The magnet of previous experiment was dropped repeatedly from a definite height on to a stone. Standard at 435.

Initial reading	275	After 6th drop	225
After 1st drop	250	,, 7th ,,	225
,, 2d ,,	246	,, 8th ,,	225
,, 3d ,,	241	,, 9th ,,	218
,, 4th ,,	240	,, 10th ,,	216
,, 5th ,,	228		

(*g.*) *Effect of Temperature.* Standard at 435. Magnet of previous experiment used.

Initial reading	216
Heated to temperature of boiling water . .	214
,, ,, of melting sealing-wax .	208

As the magnet cooled it was observed to recover a portion of the lost magnetism.

(*h.*) The magnet of last experiment was inserted within a helix, around which a powerful electric current was circulating. Standard placed at 435, balancing the steel magnetised in this manner at 345.

In the above experiments, *a—h*, the actual value in C.G.S. units of the moment of the experimental magnets may be readily calculated when the value of that of the standard magnet has been once ascertained.

36. *Distribution of Magnetism.*—To ascertain the law of distribution along a magnet we may apply several methods, as—

(1.) A Vibration Method.
(2.) A Deflection Method.
(3.) A Test-Nail Method.

The first two methods are simply applications of the principles we have described. The third method will form the subject of the next lesson.

Lesson XVIII.—The Test-Nail Method.

37. *Exercise.*—To find the distribution of force along a short bar magnet.

Apparatus.—A spring balance in one of its modifications. Fig. 37 shows one suited for the purpose. Here *ss′* is a spiral spring, having a silk cord attached to its upper end. The silk passes round a pulley mounted so as to rotate stiffly in a collar. At the end of the spiral spring is a small piece of soft iron. When the soft iron rests upon a magnet the force of attraction is measured by the amount of turning that must be given to the milled head *m* in

order to detach the soft iron. This is indicated by means of the graduated disc *d* and the fixed index *i*. To ensure that the pull from the magnet is vertical the spiral spring works within the glass guard tube *g*. The apparatus is supported from an arm which may be raised or lowered at pleasure.

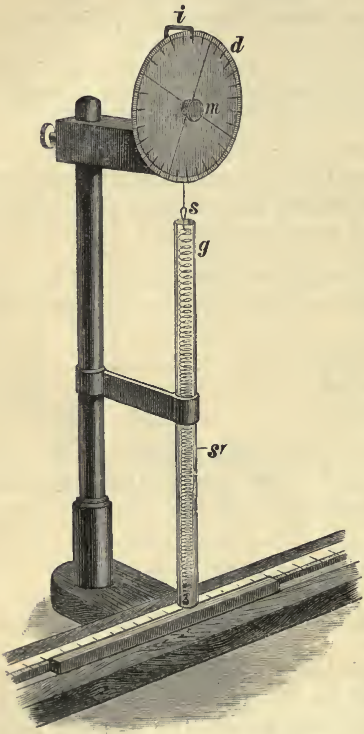


Fig. 37.—Magnetic Balance.

Theory.—If S denotes the strength of the magnet at any point, then the magnetism induced in the soft iron will be proportional to S, or equal, let us say, to KS, and hence the force necessary to detach the magnet must be proportional to S^2, or

$$F = \text{constant} \times S^2,$$
or $$S = \text{constant}\sqrt{F},$$

that is to say, the strength at any point is proportional to the square root of the force required to detach the soft iron. The method is open to the objection that the amount of magnetism induced depends upon *the coefficient of induced magnetism*, which may not, however, be strictly constant, but may vary to some extent with S. Again, the presence of the

soft iron is liable to cause a change of distribution of magnetism in the neighbourhood where it is placed.

Method.—Obtain the zero point of the balance by substituting for the magnet a piece of wood of the same size, turning the milled head until the soft iron just touches the wood. Now place the magnet in position and ascertain the number of divisions through which the milled head must be turned until the soft iron leaves the magnet. The milled head must be turned slowly without any jerks, and a number of observations must be taken at each place, especially near the ends of the magnet, where such observations are most likely to vary.

Example.—Magnet divided into 174 equal parts.

Distance from middle of Magnet=D.	F.	$\sqrt{F}$.	$\frac{\sqrt{F}}{D}$
13	9	3·0	·23
23	21	4·58	·20
33	39·5	6·28	·19
43	70	8·37	·19
53	125	11·18	·21
63	183	13·52	·21
73	308	17·55	·24

These results agree approximately with Coulomb's conclusion that for short magnets, that is to say, for magnets whose length is less than fifty times their diameter, the magnetic strength (between the end and the centre) is directly proportional to the distance from the centre. If this had been quite true the value of $\frac{\sqrt{F}}{D}$ should have been a constant quantity.

CHAPTER III.

VOLTAIC ELECTRICITY—FUNDAMENTAL LAWS AND MEASUREMENTS.

Lesson XIX.—Fundamental Experiments.

38. *Apparatus.*—Two pint Bunsen's cells placed in a box arranged as shown in plan in Fig. 38. Each cell consists of a cylindrical glazed stoneware jar P, about 10 cm. in dia-

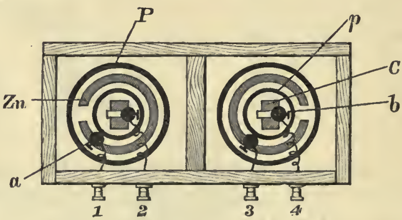


Fig. 38.—Plan of Two-Cell Battery.

meter and 15 cm. high. In this jar there is placed a cylinder of zinc *Zn*, made from a plate of zinc 14 cm. by 20 cm. that has been heated and then bent round until its edges nearly meet. Within the zinc cylinder there is placed a porous pot *p* 14 cm. high and 5 cm. in diameter made of unglazed earthenware. This porous pot contains a rod of prepared carbon C 16·5 cm. in height and 3·5 cm. by 1·75 cm. in cross-section. The zinc and carbon have attached to

them *screw clamps a* and *b*. The box for containing the battery is covered inside with pitch in order to prevent the fumes of the acid from acting upon the wood, and is provided with four binding screws numbered 1, 2, 3, 4, each of which has attached to it, inside the box, a thick copper wire covered with gutta-percha for making connections with the clamps.

The following additional apparatus and materials should be at the disposal of the student:—

Measuring vessels.
Glass funnel.
Glass tubing.
Stoneware jug with a spout.
No. 18 insulated copper wire.
No. 20 cotton-covered copper wire.
No. 30 pure iron wire.[1]
No. 30 copper wire.
Sulphuric acid.
Nitric acid.
Mercury.
Caustic soda.
File.
Emery paper.
Stiff nail brush.
3 Carbon rods, 6 to 12 in. long, about 2 in. thick.
India-rubber finger stalls.

Fitting up of the Battery.—This must be done in a draught cupboard or in the open air to prevent the fumes of the acid from affecting the operator.

Begin by removing all the clamps and clean the connecting surfaces and screws by means of a file and emery paper.

Proceed next to the making of mixtures and the *amalgamation* of the zinc. Into one of the earthenware battery jars put a solution of caustic soda and water (1 of soda to 20 parts of water by weight), and into the other some sulphuric acid diluted with water (1 of acid to 12 of water by weight). In making this last mixture in the jug, *pour* the water *first* into the jug, then gradually pour upon it the acid, stirring meanwhile with a glass rod. If the acid be put in first and the water be added to it sufficient heat might be produced by the chemical union to crack the jar. Since all the sulphuric acid of commerce contains lead sulphate which is precipitated on dilution with water,

[1] This should be kept in a bottle with quicklime.

the acid mixture will appear milky when first made. As the presence of lead is very injurious to the working of the battery it will be desirable to allow the mixture to settle and then decant off the clear liquid. A quantity of the mixture should thus be prepared and labelled "*Battery sulphuric acid.*"

The process of amalgamation is as follows:—

First, Dip the zinc into the solution of caustic soda in order to remove grease, and then wash it under a water-tap.

Secondly, Place the zinc in the dilute sulphuric acid until effervescence has commenced, then lift it out and lay it down in a flat dish.

Thirdly, Pour mercury that is free from lead and other injurious metals in a thin stream upon the inside of the cylinder, and also on the outside. Roll the cylinder about until nearly the whole surface of the zinc has a bright appearance.

Fourthly, Replace the zinc in the acid, and rub the surface with a stiff brush or with a rag, the fingers being protected in the operation by finger stalls. The whole of the zinc should be now well amalgamated. Remove it from the acid, wash it well with water, and allow it to drain.

Lastly, Collect any waste mercury and place it in a bottle labelled "*Amalgamation mixture.*"

Keep also the soda solution in a bottle appropriately labelled.

The process of amalgamation tends to make the zinc brittle and rotten if too much mercury be used. Napier (*Electro-Metallurgy*) allows $1\frac{1}{2}$ ounce of mercury for every effective square foot of zinc in the first operation, and half that weight for the second and all subsequent operations. We find that 1 gramme of mercury will thoroughly amalgamate 100 square cm. of zinc surface. Three times this quantity of mercury may be used in the actual process, of which two-thirds will be recovered by draining off.

Examination and Preparation of the Porous Pots.—The

porous pots being thoroughly clean and dry, subject them to the following test: Pour water into each pot, taking care not to wet the outside, and note the time by a watch. Then observe when first an indication of moisture appears on the outside surface of the pot, and again note the time. If the moisture appears immediately, the pot is cracked, and should be rejected. A good pot, if made of red clay, should become moist all over in about two minutes; if made of white clay, in about double the time.[1] For low resistance cells the red-clay pots are to be preferred, but they possess the serious defect of being liable to disintegration, a fault possessed in a much less degree by the white pots.

Melt some paraffin wax, and plunge the open end of the porous pot vertically into the wax until this has soaked into it through a distance of about a quarter of an inch from the open end.

This will prevent the acids from creeping up the sides, and will likewise prove especially useful in preventing the sulphate of zinc formed when the battery is in action from becoming concentrated along the rim of the jar, and there crystallising, with the effect of disintegrating the porous material.

It is an excellent plan to put a flat india-rubber band round the top of the jar. This serves to protect the paraffin and to insulate the pot from the clamp at the top of the zinc, besides enabling the experimenter to handle the pot without staining his fingers with nitric acid.

Charging the Battery.—Fix the clamps upon the carbon and the zinc, and bring the parts of the battery together. Now pour strong nitric acid through a funnel into the porous pot to within about an inch of the top. Next fill up the outer pot with battery sulphuric acid to a level *about an inch higher* than that of the acid in the inner pot, the reason for this difference of level being that the action of

[1] A good pot should have a minimum leakage of 15 per cent in twenty-four hours, according to the French standard.

diffusion tends to empty the outer pot. Connect the zinc of one cell to the wire attached to the binding-screw No. 1, its carbon to that of No. 2, the zinc of the other cell to that of No. 3, and its carbon to the remaining screw.

Finally, tighten all the clamps, and then close and fasten the box, which may now be brought into the laboratory.

Necessary Precautions with the Battery.—The student must once for all be warned that nitric acid batteries may be the source of considerable danger to delicate instruments. Hence it is better that they should not be brought into the laboratory, being only used in a draught cupboard or placed outside a window. Since, however, this arrangement is not always convenient, we may employ a tightly-fitting box, such as we have described, *provided this box be not opened in the laboratory.* The battery should be placed under the experimenter's table or bench in a position where it is not liable to be overturned.

In some schools it may be considered preferable to use a more simple form of battery in which nitric acid is not used. We shall therefore describe the bichromate battery.

The Bichromate Battery.—An ideal battery should *at any desired time* be capable of yielding a *strong and constant current.* No *primary*[1] battery hitherto invented can be said to have these qualities in a satisfactory manner. The nearest approach is perhaps found in certain forms of the bichromate battery, of which Fig. 39 represents a good type. It has two pots p and P, the former of unglazed (porous) and the latter of well glazed earthenware. Within p stands an amalgamated plate of zinc Zn, and within P are four carbon plates fastened together by a band of lead. The cells are provided with a wooden framework having an arrangement whereby the zincs may be supported out of the liquid when the battery is not required for use. To charge the

[1] Batteries are divided into two classes, *primary* and *secondary*. The latter comprise the storage cells, which require to be charged by means of a current obtained from a dynamo.

cell dilute sulphuric acid is placed within p and one of the following mixtures in P :—

Oxidising Mixture.—Dissolve 100 grammes of bichromate of potash that has been purchased in the form of a

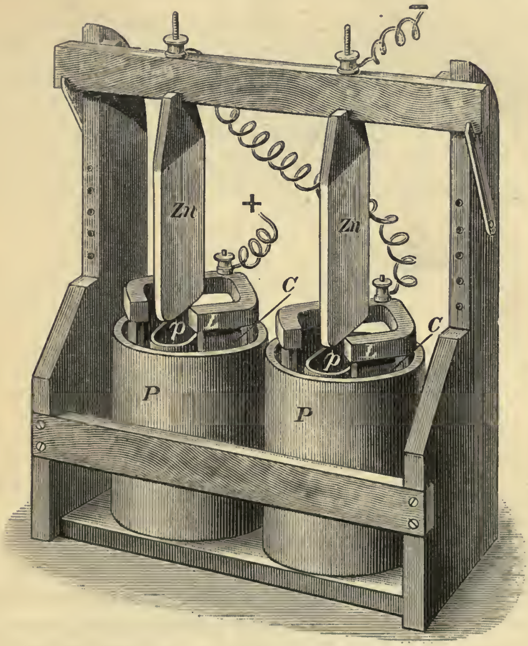


Fig. 39.—The Bichromate Battery.

fine powder in one litre of boiling water. Cool the solution and add 60 c.c. of strong sulphuric acid. This mixture acts chemically in a manner similar to nitric acid, being a strong oxidising fluid, but it is free from injurious fumes.

Instead of bichromate of potash we may use with much advantage bichromate of soda, for the soda salt does not

give rise to chrome-alums that deposit in the cell. The soda salt when obtained in quantity is much cheaper than the potash salt.

Chromic acid is likewise now beginning to replace bichromate of potash.

Preliminary Connections.—Connect together binding screws Nos. 2 and 3 (Fig. 38) by means of a short piece of wire, and attach *main* or *leading wires* to Nos. 1 and 4. For this purpose No. 18 gutta-percha-covered copper wire will be found useful. The bared brightened ends of the wire are to be put round the binding-screws, or better still, we may employ a plate of copper (Fig. 40) provided with forked ends. This

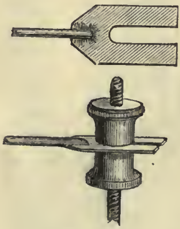


Fig. 40.
METHOD OF CONNECTION WITH BINDING SCREWS.

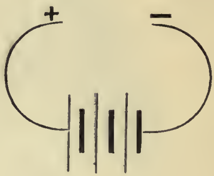


Fig. 41.
SCHEME OF BATTERY.

plan gives a better contact, and is therefore much to be preferred. Fig. 41 exhibits the manner in which the battery is usually connected. Here the thin vertical lines represent the carbons, the short thick wires the zincs, and the battery is said to be *in series*. In the diagram there are three cells, supposed to be connected together by wires going from the carbon of one cell to the zinc of the next, and so on. The end of the wire connected with the outer zinc is called the *negative pole* (written −), and that connected with the outer carbon is called the *positive pole* (written +). When these poles are connected together there will be a flow of electricity from the + to the − pole.

The battery now described should be used for the following groups of experiments :—

Group I.—(*a*) Bring the free ends of the leading wires together and then separate them ; a spark will be produced.

(*b*) Attach a file to one leading wire and rub the other pole along it ; the sparks will now be more brilliant.

(*c*) Attach a small piece of carbon rod to each leading wire, bring the carbons together and separate them, when a bright light will be produced. Observe that the carbon rods get very hot.

(*d*) Twist a piece of thin iron wire round one pole and then touch the free end of the iron wire with the other terminal of the battery ; it will be found that several inches of the wire may thus be kept at a red heat, and if of short length the wire may even be fused.

(*e*) Use fine copper wire of the same diameter instead of the iron, and notice that it cannot be heated to redness.

Group II.—*Additional Apparatus.*—Pohl's commutator or instrument for changing the direction of the current (Fig. 42) ; a magnet suspended from a stand ; a wire one mètre long stretched between the uprights (Fig. 43) and mounted on a board. With the aid of the suspended magnet set the wire in the magnetic meridian. See that the cups of the commutator contain mercury, and that the ends of the wires dipping into them are well amalgamated. Connect the ends of the wire with the commutator.

Make connections such as are exhibited in Fig. 43, on which the commutator is denoted by the cross. Trace out these and ascertain the position of the commutator switch that corresponds to a current from north to south along the wire. Call this Position I., and that which gives a current in the opposite direction Position II. Now break

the current, and then suspend by means of a fibre over or under the wire a short magnetic needle. The fibre should

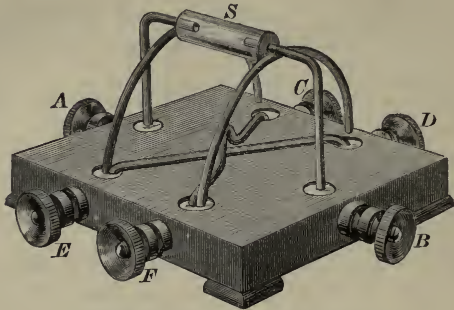


Fig. 42.—POHL'S COMMUTATOR.

The cups of the ebonite base contain mercury, and are in connection each with its nearest binding screw. The switch hinged at A and B is moved by the insulating handle S.

When the terminals of the battery are connected at E and F, or C and D, then the ends of the main circuit are placed at A and B, and *vice versa.*

In the position shown, if a current entered at E it would ascend the left curved wire, descend the lateral wire to A, pass through the main circuit to B, ascend the right lateral wire and descend the curved wire to F. When the switch is pushed back the current will traverse the horizontal wires and be reversed.

be attached to a stand so arranged that by means of a telescopic joint or otherwise the magnet can be easily raised

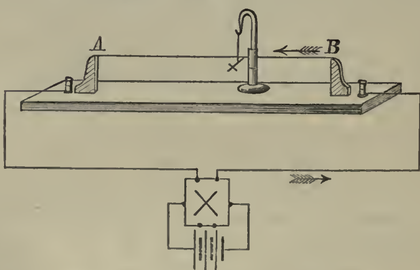


Fig. 43.—EXPERIMENT OF AMPÈRE.

or lowered. When the magnet is at rest turn the commutator into Position I. and note the direction in which

the magnet is deflected. Then turn the commutator into Position II. and again note the direction of the deflection which is produced. Proceed in this manner to verify the following table :—

WIRE HORIZONTAL.

Position of Magnet.	Position of Commutator.
	I.
Above wire . . .	North end deflected to west.
Below wire . . .	,, ,, east.
Level of wire east side .	South end dips.
,, west side .	North end ,,
	II.
Above wire	North end deflected to east.
Below wire	,, ,, west.
Level of wire east side . .	North end dips.
,, west side .	South

WIRE VERTICAL.

Position of Magnet.	Position of Commutator. I. Current up the Wire.
North pole against the wire . .	North end deflected to east.
South pole ,, ,, . .	South end ,,
	II. Current down the Wire.
North pole ,, ,, . .	North end deflected to west.
South pole ,, ,, . .	South end ,,

Exercise.—Cut out a cardboard model of a man, and test your results against the following *memoria technica.* Imagine a man to be swimming against the current, which we may suppose to *enter* in at his *head* and leave at his feet, his *face* being turned *towards* the needle. Under these circumstances the *north-seeking* pole of the needle will be deflected towards his *right* hand.

Group III.—Apparatus.—Glass tubing $\frac{7}{8}$-inch in diameter, corks, soft-iron nails, iron filings. *Experiments.*—(*a*) Take a piece of the glass tubing about $3\frac{1}{2}$ inches long, bore $\frac{7}{8}$-inch holes in two corks each about $1\frac{1}{4}$ inch in diameter. Into these holes the ends of the tubing have to be fitted to form reels.[1] Now make

[1] Turned wood reels can be used instead, as shown in the figure.

a small hole through one of the corks near the inside edge, and inserting through it the end of some No. 20 cotton-covered wire, proceed to wind this on the tube in the direction opposite to that of the hands of a watch, looking at the reel from above. About 6 inches of the wire should be passed through the hole before beginning to wind (see A, Fig. 44). Continue winding until four layers of wire are wrapped round the tube, and then bring the other end of the wire through a second hole in the cork (B, Fig. 44). Connect the ends of the wire with the battery. The helix will be found to behave as a magnet, and its polarity must be examined by means of the magnetoscope. Reverse the current and again examine the helix, which will now be found to have its polarity reversed.

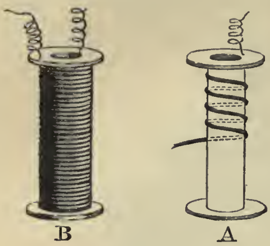


Fig. 44.
METHOD OF WINDING HELIX.

(*b*) Make a second helix, but wound in a direction the contrary to that of the hands of a watch, and then repeat the preceding experiments. The direction of magnetisation or polarity of this second helix will be found to be the opposite of that of the first.

(*c*) Notice that soft iron wires are readily drawn into the helices when the current is passing. Notice also that when the central hollow of the helix is filled up with such wires the magnetic power is greatly increased, the polarity being the same as that of the helix without the iron wires. See also if your results conform with the following rule: Look upon the helix from that end which makes the positive current appear to circulate in the direction of the hands of a watch. This end will be the S. pole and the

other the N. pole of the helix. Hence if the helix could be swung freely it would point magnetic north and south, and the positive current would at the N. pole ascend on the west side and descend on the east.

(*d*) Place the helix conveying the current vertical, with a piece of cardboard across its end. Scatter filings over it, and obtain magnetic curves with and without a soft-iron core.

Group IV.—Dip the two ends of the battery wires into a small beaker containing dilute sulphuric acid, and leave them there several minutes, the terminals not being in contact with each other. It will be noticed that one terminal becomes covered with bubbles, which collect and escape to the surface, and that this is the one connected with the *negative pole.* The other terminal meanwhile becomes cleaner and brighter, as if the acid were dissolving it. That this is really the case will be seen by the liquid becoming *blue,* owing to the formation of copper sulphate. If the action be continued sufficiently long the negative terminal will become covered with a brown deposit, which on examination will prove to be pure copper.

The general explanation of these appearances is as follows: The current decomposes the liquid in which the terminals are placed, that is to say, it decomposes the dilute sulphuric acid, the copper terminal connected with the positive pole taking the oxygen and sulphur, and producing sulphate of copper, while at the negative terminal the free hydrogen, which forms the remaining portion of the decomposed molecule, is allowed to escape.

When, however, besides free acid there is a sensible quantity of sulphate of copper dissolved in the liquid, the sulphate of copper is electrolytically decomposed, copper is deposited upon the negative terminal, and acid is reproduced, which in its turn dissolves more copper at the positive terminal or **electrode**.

We shall see afterwards what advantage is taken of this action in plating operations.

Note—Draw in your note-book diagrams illustrating the above explanations.

Group V.—Proceed now to fit up a **Voltameter,** or instrument for decomposing water and collecting the products, as follows :—

(*a*) Cut off the shank of a 4-inch glass funnel to within half an inch from the top.

(*b*) Procure a piece of platinum foil, ABCD, of the size represented in Fig. 45, place it upon a brick, and direct the blowpipe flame upon it. Whilst the platinum foil is at a bright red heat lay upon one end of it a short piece of platinum wire, EF, and then by means of a few smart taps with a hammer weld the wire to the foil. Wind the end F of the platinum wire round one end of a piece of No. 20 copper wire about 6 inches long, sprinkle a little resin on the joint, on which a fragment of soft solder has been placed, and proceed to solder it by means of a Bunsen's burner. The *electrode* will now be finished. Next make a second one of the same size.

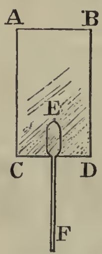


Fig. 45.
VOLTAMETER ELECTRODE.

(*c*) Fit a cork into the end of the funnel, and, piercing it with two holes by means of a knitting needle, pass the copper wires through these so that the platinum electrodes may be inside the funnel. Well warm the funnel all round, melt some paraffin wax and pour it in so as to fix the electrodes in position and cover the copper wire.

(*d*) Procure two test tubes of exactly the same size. Place the voltameter on a retort stand and pour into it some dilute sulphuric acid (say 1 part of

acid to 50 of water). Fill the test tubes likewise with dilute acid and invert them over the platinum electrodes. Finally connect the terminals to the battery by means of *clamp screws* (see Appendix). The acidulated water will now begin to be decomposed, and the student will note the following particulars :—

(1) Gases are evolved from both electrodes.

(2) The gas in the tube connected with the negative electrode accumulates twice as rapidly as that connected with the positive.

(3) The gases respond to the tests for hydrogen and oxygen, the relative volumes being those in which these gases combine to form water.

(4) By collecting both gases in one tube an explosive mixture is obtained.

Here again we have evidence of the decomposing power of the electric current, and the student will observe how peculiar must be that action which gives us all the hydrogen at the one terminal and all the oxygen at the other. We may perhaps represent to ourselves what takes place by means of the following hypothesis, due to Grotthüss: First of all we may regard oxygen as an electro-negative element and hydrogen as electro-positive. Under these circumstances the oxygen ends of the various molecules will all point to the positive terminal, to which they will be attracted, while, on the other hand, the hydrogen ends will all point to the negative terminal, to which *they* will be attracted.

Now if the electric condition of these terminals be strongly enough developed, the positive terminal will attract the oxygen particle next it, and the negative terminal the hydrogen particles next *it*, and these will be given off at the respective terminals. This is the first operation.

The next will be a change of partners. The hydrogen of the molecule next the positive electrode having lost its partner, will attach itself to the oxygen of the molecule next but one to the electrode, the hydrogen of this to the oxygen of the molecule next but two, and so on until the whole line are once more properly paired. This is the second operation.

They are not, however, yet facing the proper electrodes, for the hydrogen will be facing the positive and the oxygen the negative. They will therefore have all to turn round about their centres through 180°. This is the third and final operation. After this the same round of operations is repeated.

Note.—Draw in your note-book a diagram illustrating the above hypothesis.

Discharging the Battery.—When we have done with the battery it must be carried to the draught cupboard and there discharged. Remove the clamps, wash and dry them. Pour the nitric acid into a bottle labelled "*Old nitric acid for batteries*;" this may be used again, unless it be of a green colour. Thoroughly wash the porous pots and leave them to soak in water. Notice if any black spots appear on the zincs, and if so reamalgamate such places; then wash the zincs and leave them likewise to soak in water. By soaking the porous pots and the zincs the zinc sulphate will be removed, which would otherwise tend to block up the pores of the pots and thus disintegrate them, and would likewise crystallise on the surface of the zincs. The sulphuric acid should be thrown away, for it is sure to contain nitric acid, which is very injurious to zinc.

39. The process of chemical decomposition effected by the electric current is called **electrolysis**. The experiments of Groups IV. and V. of the previous lesson are examples of electrolysis. A very important part of electrolysis relates to the deposition of metals, hence the next

lesson will be devoted to the typical example of copper deposition.

Lesson XX.—The Daniell's Cell and Copper Plating.

40. *Apparatus.*—A Daniell's cell of the kind exhibited in Fig. 46, which forms a convenient arrangement. It consists of a glazed earthenware pot or outer vessel P, which is 13 cm. high by 9 cm. in diameter. In it stands a cylinder of zinc *Zn*, provided with three tags or tongues, *a*, *b*, *c*, and of these the last has a binding screw attached to it. These tags are formed by cutting away portions from the original sheet of zinc that has been employed to form the cylinder. The height of the cylinder is 10 cm., and its diameter 8 cm., so that when placed in the earthenware pot the zinc is supported by its tags, and the bottom of the zinc is more than 2 cm. from the bottom of the pot. Within the zinc cylinder there is a porous pot *p*, 13 cm. high and 5 cm. in diameter, and this contains a cylinder of copper *Cu*, provided with a single tag, to which a binding screw is soldered. The porous pot has its mouth coated with paraffin after the manner already described. A small flask *f*, containing crystals of copper sulphate each about the size of a small nut, is placed mouth downwards in the copper cylinder. At the bottom of the outer pot a few pieces of scrap zinc are placed; this will help to

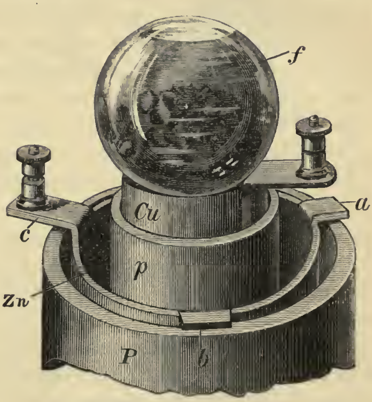


Fig. 46.—Daniell's Cell.

decompose any copper sulphate solution that diffuses into the outer pot.

The other materials required are as follows: Crystals of zinc sulphate and of copper sulphate; some telegraphic binding screws (see Appendix); india-rubber cork, $\frac{3}{4}$-inch diameter, with two holes; some plates of copper ·05 inch thick; a graduated measure; sulphuric acid, caustic soda, nitric acid; brass wire, No. 28; a glass rod, a beaker, a Bunsen's burner, and sundry materials for making solutions.

Charging the Battery.—Place a saturated solution of sulphate of copper in the porous pot. Into the flask already mentioned put crystals of sulphate of copper of about the size of small nuts, and fill it up with a saturated solution of this material, then invert it, and let it stand thus in the porous pot. The flask will now act as a supply reservoir to keep up the strength of the copper sulphate solution. Into the outer pot pour water in which some zinc sulphate has been dissolved (1 part of zinc sulphate by weight to about 20 parts of water). The battery will now be ready for use. Next connect the zinc and the copper by means of a short wire and leave the cell thus for some time with the current passing. In this condition it is said to be *short-circuited*, which process will help to bring the cell to a normal state of working.

Fitting up a Plating Bath.—Fig. 47 exhibits the requisite arrangement. Here *ab* is an india-rubber cork, having two unconnected holes, an upper hole at the right, and a lower one at the left. Into the hole at *b* there is passed the shank of a telegraphic binding screw, which serves to support a copper plate A by means of the tag *d*, and to connect it with the wire from the positive terminal of the battery. This large plate is called the **Anode.** Into the hole at *a* passes the shank of a double binding screw, formed by uniting together two ordinary binding screws. This serves to support the plate C, which must be smaller than A, and which forms the main *cath-*

ode, as well as a small **Test Cathode** T, and these are to be connected with the negative terminal of the battery. The whole arrangement is supported in a glass battery jar by means of brass wire, as shown in Fig. 47. This jar has to be filled with liquid, whose composition will be afterwards described. We may here mention that when in action the copper deposit goes from the anode to the cathode, and hence the propriety of these names.

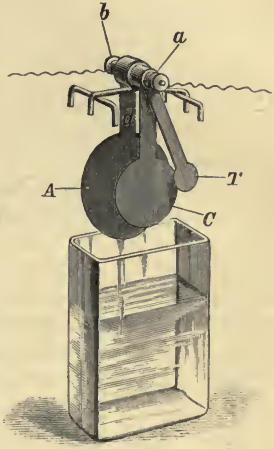


Fig. 47.—PLATING BATH.

Cleansing the Copper Plates.—In the *first* place a *scratch brush* (Fig. 48) should be made. This can be readily done by driving into a board two long nails about 6 inches apart, and then winding fine brass wire continuously from the one nail to the other. Then bind the strands together by wire, and cut off the ends. The arrangement may now be thrust through a hole in a cork, in order that it may be provided with a handle, and we shall thus have a scratch-brush with two ends. *Secondly*, make a *lifting hook*, which is simply a rod of glass bent into the shape shown in Fig. 49, and provided at one end with a cork handle. *Thirdly*, prepare the following cleansing liquids, and label them as under :—

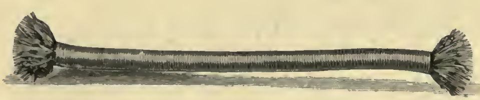


Fig. 48.—SCRATCH BRUSH.

No. 1. *Alkaline Liquor for Cleansing Copper.*
1 part by weight of caustic soda.
10 parts by weight of water.

No. 2. *Sulphuric Acid Liquor for Cleansing Copper.*
1 part by volume of sulphuric acid.
10 parts by volume of water.

No. 3. *Dipping Liquor for Cleansing Copper.*
1 vol. of impure nitric acid (residue from battery).
1 vol. of water.

No. 4. *Brightening Liquor for Cleansing Copper.*
Strong nitric acid, with a few drops of strong hydrochloric acid added.

Enough of these solutions should be prepared to cover the copper plates when they are placed therein. No. 1 should be contained in a porcelain evaporating basin, and the other solutions should be in glass beakers. *Fourthly*, the copper plates may now be cleansed as follows: (*a*) By means of the scratch-brush thoroughly clean both sides of the plates, going over the surfaces several times until the striæ run into each other; (*b*) wash each plate with water under the tap, rubbing it well with the fingers or with a rag; (*c*) boil the plate in the alkaline liquor No. 1. This will cause a discoloration, owing to the formation of an oxide. Remove the plate by means of the *lifter*, which should be used throughout the subsequent operations. Wash the plate well under the tap, then carry it to liquor No. 2, in which it should remain sufficiently long to enable the acid to dissolve the dark-coloured oxide. Again wash it with water, and then place it in liquor No. 3 for about 15 seconds, after which it must be washed and placed for a few seconds in No. 4, and then quickly washed with *distilled* water. The plate should be now very bright and clean. If it is not so, the processes must be repeated. Let the

Fig. 49. Lifting Hook.

plate now be preserved in a dilute solution of copper sulphate until required for use.

Deposition of the Copper.—The liquid with which the depositing bath must be charged is obtained by dissolving 100 grms. of copper sulphate in 500 cc. of water. Let it be boiled in a beaker until all is dissolved, and when cold let 25 grms. of sulphuric acid be added. The liquid should be bottled and labelled "*Copper depositing liquid.*"

Next place as much of this liquid in the depositing bath as will well cover the plates, and then connect the plates with the proper battery poles, attaching the negative terminal wire to the cathode or smaller plate, and the wire from the positive pole to the anode or larger plate. Now, place the apparatus in a place where it will not be disturbed and cover it up to keep out dust and prevent evaporation. The liquid should be stirred occasionally. The progress of the deposition may be ascertained by examination of the test plate.

In the course of a couple of days a bright copper deposit will be obtained on the cathode, whilst the anode will be found to be covered with a dark substance resembling mud.[1] When a sufficient deposit has been obtained, remove the cathode, wash it well, dry, and preserve it for future experiments.[2]

41. *The Galvanoscope.*—The existence of an electric current may be proved by reference to its (1) heating, (2) lighting, (3) chemical and (4) magnetic effects. An instru-

[1] This substance is of complicated composition. Besides containing disintegrated copper it may contain the impurities of commercial copper, such as tin, antimony, sulphur, nickel, silica, selenium, gold, cobalt, iron, and lead.

[2] For further information the student should consult the various treatises on electro-plating, such as:—*Practical Guide for the Gold and Silver Electroplater, and the Galvanoplastic Operator*, by Dr. Wahl. London: Sampson Low, 1883. *Art of Electro-Metallurgy*, by Dr. Gore. London: Longman and Co. Muspratt's *Chemistry*, new ed., p. 792, Article "Electro-Metallurgy," etc.

ment arranged for the exhibition of any of these effects would, properly speaking, be a *current-indicator*, *detector*, or **Galvanoscope.** But as the magnetic effects produced by the direct action of a current on a freely suspended magnet are by far the most convenient for observation, galvanoscopes are almost invariably based upon the observation of the deflection of a magnetic needle. The methods of construction of galvanoscopes are extremely various. They may roughly be classified into *Vertical Galvanoscopes* and *Horizontal Galvanoscopes.* Fig. 50 shows a vertical galvanoscope of the kind largely used by telegraphic engineers, and called by them a **Detector.** The instrument consists of a vertical coil wound at right angles to the plane of the paper, within which is a pivoted magnetic needle. The needle is loaded so as to rest in a vertical position. Fastened to the same axis as the needle is a pointer, which moves over a circle placed between the pointer and coil, graduated into degrees. When a current passes, this needle, with its pointer, tends to place itself in a horizontal position.

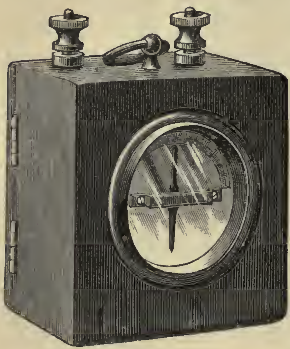


Fig. 50.
THE VERTICAL DETECTOR.

It may be asked how far an instrument such as a detector may be used as a current measurer or **Galvanometer.** If the angle of deflection of the needle were strictly proportional to the current passing through the coil, then the instrument would be of great value in comparative measurements. But this is by no means the case, nor can the indications be valued by the help of any simple rule. In order, therefore, to render the instrument of service, it must be submitted to the process of

Calibration. We shall later on describe the necessary process, and meanwhile confine ourselves to the assumption that the greater the deflection the greater must be the current circulating in the coils. This assumption will be made in the next lesson, which deals with some further fundamental experiments made with a horizontal galvanoscope.

Lesson XXI.—The Galvanoscope.

42. *Apparatus.*—A simple galvanoscope, or the following materials for fitting one up, will be required: A tooth-powder box about 3 inches in diameter, four binding screws, No. 28 silk or cotton covered wire, 6 inches of $\frac{1}{2}$-inch copper strip, wood for making a simple reel, namely, a strip 9 inches by $\frac{1}{4}$ inch by $\frac{1}{2}$ inch, a magnetic needle 2 inches long provided with an agate cap, a sewing needle for pivot, galvanometer card or card-board for making it, a piece of common window glass, thin board ($\frac{1}{8}$ inch thick) on which to mount the card.

Making, Winding, and Fitting the Reel.—Divide the strip of wood into three equal oblong pieces, and fit them together in order to form a reel. Trim the ends so as to make the reel fit somewhat tightly into the box. Make a small hole at one end of the reel and pass through it 3 inches of wire. Then wind continuously until the reel is nearly filled with wire. Finally, pass the other end of the wire through a second hole in the reel, then fit the reel into the box. Pass the ends of the wire through holes in the lower part of the box, and connect them with binding screws screwed into the box. The bright ends of the wire may be put round the ends of the binding screws, and then firmly held in their place by screwing the binding screws well into the wood. It is better still to make a soldered contact, but if the binding screws are firm this will not be necessary.

Mounting the Card.—Gum or glue upon a thin board a card graduated into degrees. Cut the board into a circular shape so as just to fit inside the box. At its centre fix the point of a needle so as to project upwards above the board for about quarter of an inch or less. Upon this point the agate cap of the magnetic needle is supposed to rest.

Fitting the Lid.—Mark off a circle 2 inches in diameter on the lid by means of compasses, and then cut out a hole having the circle marked as its boundary. Take off the rough edges by means of a file and sand-paper.

Next place the board which has the scale attached to it on a sheet of glass, and cut the glass round its edge by means of a diamond or substitute for a diamond. Snip off the glass with pincers; the glass ought now just to fit inside the lid.

Putting the Pieces together.—In the first place adjust the card in the box so that the zero line of the graduation shall lie along the direction of the strands of the wire. Put the needle on its pivot, and cover the whole with the box-lid. The instrument is now complete. Before being used it must be placed in such a position that the needle points to zero, in other words, the strands of the wire as well as the needle must lie in the magnetic meridian. G. of Fig. 51 shows the completed galvanoscope.

Use of Copper Strip.—Where strong currents have to be observed, it will be necessary to make use of a copper strip, through which, and not through the wire of the galvanoscope, the current must be passed. In this case the galvanoscope as above described, being properly pointed, ought to be placed on the wooden block to which the copper strip is fastened. In the arrangement sketched in Fig. 51 the strip of copper is bent so as to form the three sides of a square. It is pivoted to the wooden block so as to move stiffly. This is done by screwing the binding screws through holes in the copper into the wood. According to the strength of the current the copper strip must

be turned round its bearings into a plane more or less oblique to that of the block, this obliquity being greatest when the current is strongest, and least when the current is weakest. Or we may, by means of a sliding arrangement, place the galvanoscope at a greater or less distance from the copper strip. In Fig. 52 the copper strip is mounted on a wooden hoop, and the galvanoscope is mounted so as to slide on a graduated platform. By either of these arrangements, or by a union of both, we can bring the most powerful currents within the range of the scale of the galvanoscope.[1]

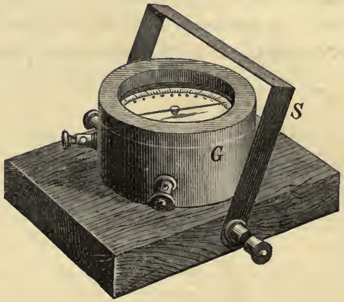


Fig. 5
GALVANOSCOPE WITH COPPER STRIP.

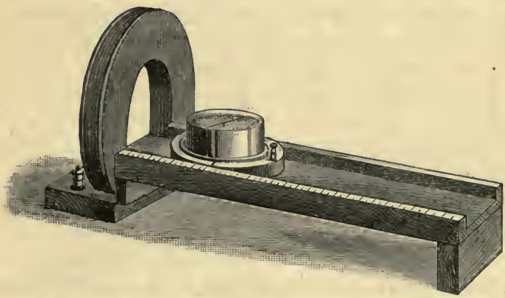


Fig. 52.—SLIDING METHOD OF CHANGING SENSIBILITY.

Fitting up the Apparatus.—The copper strip must be

[1] The former of these arrangements exhibits the principle of Obach's galvanometer, the latter the principle of Thomson's current meter, instruments which are employed in measuring currents of different strengths.

connected with the battery by means of the appropriate binding screws. When in action the copper strip must lie in the plane of the magnetic meridian. The arrangement may, if necessary, be firmly fixed to the table by a wooden clamp. The battery and commutator must be east or west of the galvanoscope (see Fig. 53), and the leading

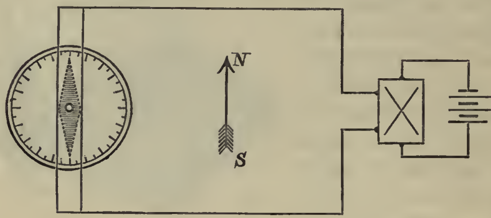


Fig. 53.

wires should remain in a fixed position during the performance of the experiments. Of these the following are examples, which were all made by means of the copper strip :—

Experiment I.—One cell was found to give a deflection

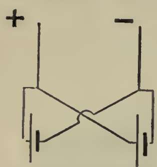


Fig. 54.—Two Cells in Multiple Arc.

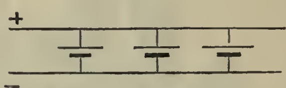


Fig. 55.—Cells in Multiple Arc.

of 48°, whilst two cells in series gave a deflection of 49°, or very nearly the same as before.

Experiment II.—The two zinc terminals were connected together, and the two carbon terminals were likewise connected together, so as to form one large cell (see Fig. 54). This method of connection is known as that of *multiple arc* (where many cells have to be arranged in this manner,

it is best to place them as shown in Fig. 55). It was found that the two cells in multiple arc gave a deflection of 62°.

Experiment III.—A piece of carbon rod, 8 inches long, placed in the circuit reduced the strength, so that one cell now gave only 16°, while two cells in series gave 28°, thereby showing that, when there is a resistance external to the battery, the current is increased by adding to the number of the cells.

Experiment IV.—It was shown that the greater the length of carbon rod in circuit, the less was the deflection.

Experiment V.—Two carbon rods of the same length placed alongside each other gave a greater deflection than one rod alone.

Experiment VI.—A piece of iron wire was coiled in a spiral and placed in the circuit. The deflection was noted, and then the iron was heated by means of a spirit lamp. Thereupon the deflection became less, but when the wire was allowed to cool the needle returned to its previous position.

43. *Theory of the Battery.*—It may here be desirable to give a short account of the principles of action of the voltaic battery, premising that in all probability these are not yet fully understood, so that any statement we make must only be regarded as a working hypothesis. If a zinc rod or wire be soldered or closely united to a similar copper rod or wire, an electric separation is produced at and over the joining surfaces, in virtue of which the zinc becomes positively and the copper negatively electrified. This electrical difference is not, however, great, and its existence can only be experimentally verified by means of a delicate electrometer. Imagine now (Fig. 56) a circuit of the following nature, namely a thick semicircular zinc rod soldered or united at two junctions to a similar copper rod. Shall

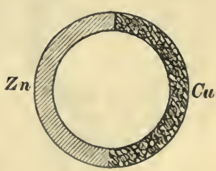


Fig. 56.

we have a current from this arrangement? Unquestionably not. At the upper junction there is no doubt a source of electric irritation, in virtue of which positive electricity is driven to the zinc or left-hand side, and negative electricity to the copper or right-hand side, and if these two electricities could be allowed freely to unite in the remainder of the circuit, we should certainly have a current as long as the electric irritation was kept up. But this is not the case, for the lower junction is a similar source of electrical irritation, and will prevent the union of the two electricities, so that what we shall finally have will be, not a current, but a distribution of statical electricity, in virtue of which the zinc will remain positively and the copper negatively electrified. Before we can get a current we must be able to retain the irritation at the one junction and neutralise it at the other.

It is this which is accomplished by means of the battery liquid. Suppose that we dispense with the lower junction and allow the rods to swell out into two plates or terminals of their own material, which are to be immersed in a vessel containing dilute sulphuric acid (Fig. 57). A molecule of this dilute acid may be regarded as being composed of two members or parts, one of these containing the oxygen, which we may regard as negatively electric, and the other the remainder of the molecule, including the hydrogen, which we may regard as positively electric. The first effect of the immersion of the electrodes in dilute acid may be regarded as a polarisation or pointing of these liquid molecules after the manner which we have previously described, namely, the ends containing oxygen pointing to the zinc, and the ends containing hydrogen to the copper terminal. Now, if the positive electricity of the zinc terminal be more intense

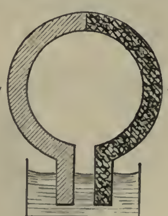


Fig. 57.

than that of the hydrogen portion of the dilute acid molecule, the oxygen portion will leave this hydrogen portion and will unite with the zinc, which will thus be oxidised, and, in like manner, at the other end the hydrogen portion of the dilute acid molecule will go to the copper terminal, carrying its positive electricity with it. By this means negative electricity will constantly be carried to the zinc and positive electricity to the copper terminal, so that the electric difference of these terminals will be neutralised. Meanwhile we may imagine that at the upper junction, the source of electric irritation continuing to exist, a constant supply of positive electricity is carried down the zinc side and a similar supply of negative electricity down the copper side, both of which are, as fast as they descend, neutralised after the manner we have now described. But a current of negative electricity flowing down the right-hand side is equivalent to a current of positive electricity flowing up, so that, taking both sides together, we have virtually a current of positive electricity flowing round the circuit in a direction the opposite to that of the hands of a watch, and passing in the liquid from the zinc to the copper.

The combination of the zinc with the oxygen, and the solution of the oxide in the liquid, involves of course the gradual wasting away of the zinc, which may be said to be slowly burned in a liquid manner. This burning is the source of energy in the arrangement, to which the zinc serves as fuel, while the peculiar construction of the circuit is adapted to convert this energy into the form of a current of electricity. We have in fact to look for the *mechanical equivalent* of the energy displayed to the burning of the zinc, and for the *peculiar form* which this energy takes to the arrangement of the circuit. If we did not amalgamate the zinc there would probably be a difference in hardness and chemical composition, between different parts of the same plate. These differences would give rise to local currents,

so that the energy due to the combustion of the zinc would be partly spent on these local currents, to the weakening of the main current of the battery, which it is our object to strengthen as much as possible. Thus amalgamation of the zinc, by equalising the chemical composition all over the plate, prevents the formation of these local currents, so that the whole energy of the combustion is directed towards the main current. But it will be asked, What becomes of the hydrogen which is set free on the copper plate? It cannot, of course, combine with the copper, and will ultimately no doubt form bubbles and escape to the surface. Meanwhile, however, it may envelop the copper terminal, and, by means of the tendency to send a current in the opposite direction or **Polarisation** thus produced, act detrimentally upon the production of the current, which will become quickly enfeebled from this cause.

It becomes therefore a matter of importance to prevent this deposition of hydrogen and consequent polarisation, so as to obtain a constant current from our battery. This is done in Bunsen's battery, which we have just been describing. Here, under ordinary circumstances, while the amalgamated zinc would be gradually oxidised by the dilute sulphuric acid, the hydrogen would be deposited on the carbon plate, which plays the part of the copper, and thus polarise it; but this deposition is prevented by immersing the carbon plate in strong nitric acid enclosed in a porous cell. By this means the nascent hydrogen is immediately oxidised by the oxygen of the acid, and its deposition upon the carbon plate is effectually prevented. The nitric acid will of course, owing to the loss of oxygen, become gradually changed in its composition, and useless for the purpose.

Exercises.—

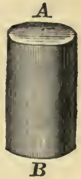
1. Sketch and explain the *electric* action that causes the battery current.
2. As far as *energy* is concerned, what is the current due to?

3. What is the use of amalgamating the zincs?
4. Explain the part played by the porous cell.

44. *Electromotive Force.*—We have here spoken of the electric difference which is continuously kept up at the junction of dissimilar metals; this may be termed (for the present purpose) the **Electromotive Force** of the arrangement, and is generally denoted by the letter E. This electromotive force may be regarded as chiefly, at all events, depending upon the electro-chemical difference between the two plates, so that zinc and copper would give one value of E, zinc and carbon a second, zinc and platinum a third, and so on. Suppose we confine ourselves to zinc and carbon, then, if we have a single cell, its electromotive force will be E. If, however, we have two cells in series, that is to say, the zinc of the one cell being connected with the carbon of the next, we shall have a total electromotive force equal to 2E,—if three cells in series, 3E, and so on.

45. *Ohm's Law.*—It must not, however, be imagined that if two circuits have the same electromotive force the current will necessarily be the same in each. This leads us to discuss the law which regulates the rate of flow, intensity, or strength of the current produced, known as Ohm's law, because it was discovered by Ohm, a German physician.

A



B

Fig. 58.

In order to explain this law, imagine that we have a thick cylindrical metallic rod (Fig. 58), of which the upper cross-section A is kept at an electric potential or level different from that of the lower cross-section B. This difference of electrical level we shall call E. In consequence of this electrical difference between the top and bottom being kept up at these places, there will be a continued flow of electricity from the top to the bottom, the strength of which will depend amongst other things upon the value of

E; double E and you double the flow, make E three times as great and you increase the flow in the same proportion, and so on. Thus the strength of the current or C is *proportional to the electromotive force or E.*

In the next place, the flow of electricity will be *proportional to the cross-section* of the rod at A, so that if we double the cross-section we shall double the flow. The double cross-section virtually makes the single rod into two rods, and this law hardly requires further explanation. The next point is that if we double the length of the rod we halve the flow, other things being the same—in other words, the flow is *inversely proportional to the length* of the rod. To prove this, let us suppose that the rod in the above diagram is cut by an imaginary cross-section half-way between the top and the bottom. The electrical difference between this section and the bottom will only be one half of that between the top and the bottom, or it will be $\frac{E}{2}$, and yet, since we have not altered the state of things, we shall have the same current C as before in the lower half of the rod. In other words, we may either regard the current C as produced by an electrical difference E between the top and bottom of the rod, or by an electrical difference equal to $\frac{E}{2}$ between the middle and bottom of the rod. Now had there been an electric difference = E between the middle and the bottom, we should obviously have had a double current—in other words, for the same electrical difference the current is inversely proportional to the length of the rod.

Finally, the amount of current will depend *upon the nature* of the rod—if it be of copper there will be a large flow for a small electrical difference, if it be of wood the flow will be much smaller, and if of ebonite there will be scarcely any flow whatever.

All that we have now stated is conveniently expressed by Ohm's law and the other laws associated with it. The

following is a statement of Ohm's law: Let C represent the strength of the current in a circuit, E the electromotive force, and R the resistance this current experiences from the materials of the circuit, then

$$C = \frac{E}{R}.$$

To define the resistance, or that which impedes the flow of electricity, we must bear in mind what we have already indicated above: (1.) that the conductivity is directly, and hence the resistance is inversely, proportional to the cross-section of a rod or wire; (2.) that the conductivity is inversely, and hence the resistance is directly, proportional to the length; (3.) that the conductivity depends on the substance of which the rod or wire is composed, each substance having its own specific conductivity; hence the resistance also depends on a specific resistance, which will vary inversely with the specific conductivity. In fine, resistance may be regarded as the reciprocal of conductivity, so that we may either assert that the current is jointly and directly proportional to the electromotive force and the conductivity of the circuit, or directly proportional to the electromotive force and inversely proportional to the resistance.

The resistance of a circuit is usually divided into two parts—the internal or essential resistance of the battery, consisting chiefly of that of the liquid into which the plates are immersed, and the external resistance, which may be varied according to circumstances. The laws now given apply equally to the internal and to the external resistance. If we denote the former by R and the latter by r, then Ohm's law will stand as follows:—

$$C = \frac{E}{R + r}.$$

We may now apply Ohm's law to give an explanation of the experiments of Lesson XXI.

In the first place, for one cell, without any external resistance except the copper strip, we shall have $C = \frac{E}{R}$, while for two such cells in series we shall have $C = \frac{2E}{2R} = \frac{E}{R}$. Thus both theory and experiment agree in demonstrating that the current is the same in these two cases—as a matter of fact the galvanoscope indications were 48° and 49°.

Again, when the two cells are connected together in multiple arc, we have virtually one large cell of a double cross-section. Here the current will be, since the resistance is halved owing to the cross-section being doubled, $C = \frac{E}{\frac{1}{2}R} = \frac{2E}{R}$. Accordingly we ought to have a double current, and, as a matter of fact, the galvanoscope indications increased from 48° to 62°. We must not, however, in the meantime attempt to use these numbers to give us an accurate measurement of the comparative intensity of the current in the two cases; this will come afterwards, when we describe the galvanometer. Suffice it, however, that both by theory and experiment the current is much larger when we have the two cells connected in multiple arc than when we have a single cell or two cells in series. Thirdly, when we interpose a considerable external resistance, such as a piece of carbon rod, not only is the current greatly reduced in strength (from 48° to 16°), but the two cells in series give us decidedly more than a single cell, the numbers being 16° for a single cell, and 28° for the two cells in series. This follows at once from Ohm's law, which will give us for a single cell under these circumstances $C_1 = \frac{E}{R+r}$, and for two cells $C_2 = \frac{2E}{2R+r}$. Now if r is considerable, C_2 will be decidedly greater than C_1, and if it be very great compared to R, C_2 will be nearly double of C_1.

Finally, we see from Experiment IV. that a rise of temperature increases the resistance of an iron wire, and the same law will hold for other metals.

When the external part of a circuit is composed of

varying resistances, we must remember, in applying Ohm's law to it, that the same quantity of electricity passes in one second through every cross-section of the circuit. For if this were not the case, more positive electricity might be carried into some region than was carried out of it, so that positive electricity would there accumulate, or less might be carried in than was carried out, so that the region would become more and more negative. But both of these suppositions are inadmissible, inasmuch as when a current is established we have a constant state of things. We must therefore suppose that the quantity of electricity passing any cross-section in unit of time, or, in other words, the current, is *constant throughout the circuit.* Now under these circumstances, what we have already said will lead the reader to infer that the difference of potential (which we shall take to be the cause of the electromotive force) between any two points in a circuit must so dispose itself as to be proportional to the resistance between these points, so that the greater the resistance, so much the greater is the electromotive force. In other words, we have in the whole circuit a given electromotive force E to dispose of, and this must be distributed along the circuit, so that the force between two points shall always be *proportional to the resistance* between these points.

Exercises.—

1. Define Ohm's law.
2. Explain your own experiments of Lesson XXI. in accordance with Ohm's law.

46. *The Units of Theory and Practice.*—Ohm's law may be written in three ways :—

$$C=\frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$E=CR \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$R=\frac{E}{C} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If in (1) $E = 1$ and $R = 1$, we define

Unit current as the current in a circuit with unit E. M. F. and unit resistance . . . . (4)

If in (2) $C = 1$ and $R = 1$, then we define

Unit E. M. F. as the E. M. F. in a circuit with unit current and unit resistance . . . . (5)

If in (3) $E = 1$ and $C = 1$, we define

Unit resistance as the resistance in a circuit with unit E. M. F. and unit current . . . . (6)

Having then fixed upon independent values for any two of the units, the third will be determined by one of the definitions (4), (5), or (6). We are at liberty to select any units we please. Thus, for instance, the unit current might be that produced by a Daniell's cell of a certain construction and size when its poles were connected by a specified wire; and the unit of resistance might be that between the ends of a cylinder of pure silver of specified diameter and length. But every one is now agreed that it is desirable that the units should be derived from the fundamental units of length, mass, and time adopted in this work, namely the centimètre, the gramme, and the second. Accordingly methods have been devised of defining the electrical units with reference to these three fundamental units.

The units so obtained are of very inconvenient magnitude for practical purposes, and hence **practical units** have been chosen by taking a submultiple of the unit of current and multiples of the units of E. M. F. and resistance. Thus are obtained:—

The ampère	$= 10^{-1}$ of the C. G. S. unit of current.	
The volt	$= 10^{8}$,, ,,	E. M. F.
The ohm	$= 10^{9}$,, ,,	resistance.

The units which we are here discussing are called **Electromagnetic Units**, to distinguish them from units of dif-

ferent nature called **Electrostatic Units**, which are derived from the effects of electrostatic repulsion and attraction.

It will be seen from the numerical values above given that if we have a circuit in which the resistance is one ohm and the E. M. F. one volt, then the strength of the current will be one ampère; for $\frac{10^8}{10^9} = 10^{-1}$.

Ohm.—A Committee of the British Association found that the resistance of the ohm is represented nearly by the resistance of a column of pure mercury 105 cm. long and 1 sq. mm. in section at 0° C. They caused coils of an alloy of silver and platinum to be issued as standards. Resistance coils based on these standards are called B. A. ohms. Recent experiments of Lord Rayleigh and others prove beyond doubt that the B. A. ohm is more than one per cent too small. The B. A. ohm therefore can only really be regarded as an empirical unit, just as is the case with the standard mètre. An attempt is, however, being made to substitute for the old standards new ones of correct value. These are called *True Ohms*, sometimes *Rayleigh Ohms*. In accordance with the recommendations of a Congress held at Paris in 1884 a *legal ohm* is defined to be the resistance of a column of pure mercury about one centimètre longer than that defining the B. A. ohm, or 106 cm. More exactly the relation between the units is

1 Congress ohm = 1·0112 B. A. ohm.
1 B. A. ohm = ·9889 Congress ohm.

In Germany the Siemens unit or S. U. is largely used. It is supposed to denote the resistance of a column of pure mercury 1 sq. mm. in section and 1 mètre long at 0° C.

1 S. U. unit = ·9540 B. A. ohm.

A megohm is one million ohms. A microhm is one millionth of an ohm.

Volt.—

1 Congress volt $=1\cdot0112$ B. A. volt.

A Daniell's cell has approximately an E. M. F. of one volt.

Ampère.—The ampère in common use being dependent on the ratio of the volt to the ohm, is left unchanged, and has the same value as the Congress ampère.

A milliampère is one thousandth of an ampère.

Exercises.—

1. Define unit current.
2. What is an *ampère*, *volt*, and *ohm*?
3. Distinguish between a "B. A. ohm" and a "legal ohm."
4. Find the number of microhms in a megohm.
5. Convert 5000 C. G. S. units of current into milliampères.

47. *The Mirror Galvanometer.*—To take advantage of Ohm's law for electrical measurement the student must be provided with a galvanometer. The best form of galvanometer will be one in which *currents are simply proportional to the deflections.* This is the case with the mirror galvanometer, an instrument of extreme value to the electrician.

In the following lessons it will be necessary for the student to have a mirror galvanometer of simple construction. The student may easily learn how to put together such an instrument, and it is desirable that this should be attempted by all students.

Lesson XXII.—Construction of Mirror Galvanometer.

48. *Materials.*—A wooden base B (Figs. 59 and 60) 8 inches in diameter and 1 inch thick. A pillar P, 3 inches in diameter and 4 inches high, bored with a small hole passing along its axis. A reel R, 3 inches in diameter and $1\frac{1}{2}$ inch thick, with flanges of half an inch and a

central hole $1\frac{1}{4}$ inch in diameter, with a small recess on one face. A plug to fit the hole of the reel. The reel with plug is seen in the two upper figures of Fig. 61. The

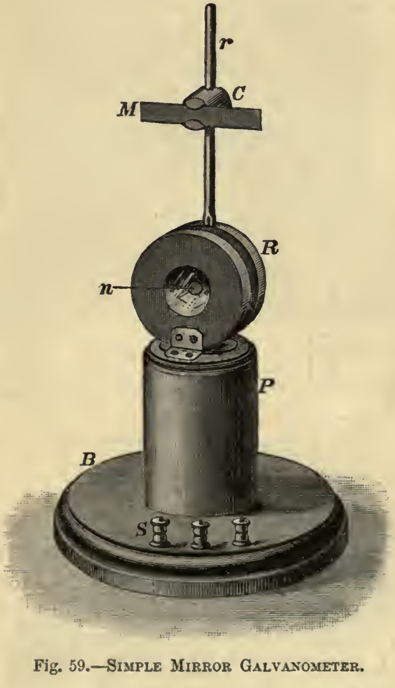


Fig. 59.—Simple Mirror Galvanometer.

above may be prepared by any wood-turner. A round piece of glass for window, to fit the recess in the reel. Bobbins of No. 28 S.W.G. silk-covered, and No. 20 S.W.G. cotton-covered, wire. Three binding screws (No. 3 telegraph binding screws). A brass rod r to support the *directing magnet* M, which may be of crinoline steel, and which is

fixed to a cork C. The cork slides up or down the rod. The *magnetic needle for suspension* requires to be attached to the back of a small mirror. It has aluminium foil for a damper and a cocoon fibre for suspension. The magnetic needle is made of watch spring.

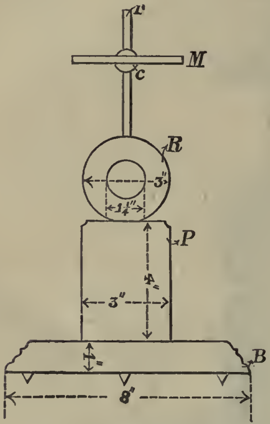


Fig. 60.
DIMENSIONS OF MIRROR GALVANOMETER.

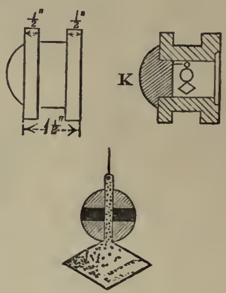


Fig. 61.
PARTS OF MIRROR GALVANOMETER.

Scale, Lamp, and Lens (Fig. 62).—The scale requires three pieces of wood. The base B—16 inches × 6 inches × 1 inch thick. The front A—16 inches × 9 inches × $\frac{1}{2}$ inch thick. The shade S—16 inches × 4 inches × $\frac{1}{2}$ inch thick. The front has a $\frac{3}{4}$-inch hole *h* $7\frac{1}{2}$ inches from the bottom. A paper scale *ab* 16 inches long is divided into millimètres. The lamp is a small paraffin lamp P that may be hooked on to the scale, which is provided with two staples for the purpose. A lens of 5-inch focus is fitted on a cork supported by a bottle L laden with shot. The lens is used for focusing (see Fig. 62).

Construction.—I. Winding the Reel.—This may be done

by hand, but it is far more expeditious to employ the simple machine of Fig. 63. The reel R is slipped upon

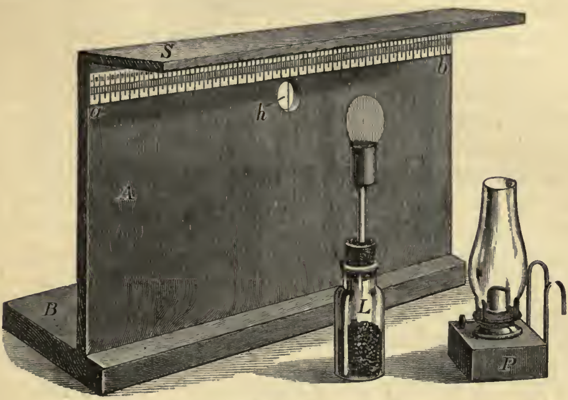


Fig. 62.—Scale, Lamp, and Lens.

the somewhat conical axis, where it is wedged firmly. A

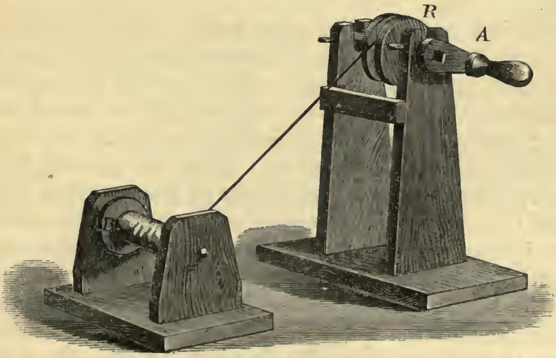


Fig. 63.—Winding the Reel.

few turns of wire are then wound round the axis, and the wire is then wound regularly on the reel with a moderate

tension from the bobbin B, which may be mounted on a metal axis supported by two uprights so as to revolve. The winding machine and bobbin holder should be clamped or screwed down to the table. First wind one layer of No. 20 wire, then give it a coat of melted paraffin applied with a brush, then wind a second and third layer, applying paraffin to each. Leave about 12 inches of wire for making connections; this may be wound round the axis. Secondly, replace on the winding machine the bobbin of No. 20 wire by the bobbin of No. 28 silk-covered, and wind on about 300 turns. Paraffin will not be required with this wire, the insulation of the silk being sufficiently good if the wire be not roughly handled. Should any bare places appear they should be covered with tissue paper that has been steeped in paraffin.

The free ends of the wires should be dipped in paraffin, and they should be run together so as to leave the reel at the same place. A piece of ribbon is wound round the reel to keep the wire in its place and as a protection from dust.

II. Fit together the woodwork, screw the pillar to the base, fasten the reel on the top of the pillar by brackets of zinc or brass, run the wires down through the hole in the pillar and through that in the base, solder the end of the No. 20 wire, and the beginning of the No. 28 to the same binding screw, the other ends going to separate binding screws placed one on each side of the common binding screw; thus the three screws will serve for the two coils, and by using the extreme screws, the two coils may be used in conjunction. It is best first to solder short lengths of wire to the shanks of the binding screws before passing them through the holes in the base, and then solder the ends of these wires to the free ends of the coils, for it is difficult to solder the latter directly to the short shanks of the binding screws. The base may either be supported by levelling screws (three window-fasteners do very well)

or raised until it is horizontal by means of three small wooden feet.

III. The next thing will be to make the needle. Harden and magnetise $\frac{1}{4}$ inch of watch spring, and fix it to the back of a small mirror by wax. Cut out a piece of aluminium foil in diamond shape, leaving a tag to which the mirror must be fixed. The completed needle is seen in Fig. 61, where the circular glass mirror, the horizontal magnet, and the diamond-shaped aluminium damper—all these being in the same plane—will be recognised. A hole must be pierced in the end of the tag with a small needle for the reception of the suspending fibre.

Notes.—(1.) It is perhaps better to use a large disc of aluminium as damper, in order that the air resistance may be as much as possible. (2.) The mirrors are best obtained from the opticians. They should be ground concave of a mètre focus. The mirrors made by silvering microscopic glass by one of the chemical processes are generally not satisfactory.

IV. Fix a small piece of wire to the inner portion of the plug K (Fig. 61), and suspend the needle from it by means of a single fibre of cocoon silk. This operation is one requiring considerable skill and care; it does not, however, require special description.

V. Next arrange the cork with the directing magnet on the rod. Put in the window with a little putty.

VI. Fasten the scale together, stretch a wire across the hole, and glue the paper scale upon the cross-piece.

Setting up of Galvanometer and Scale.—Place the instrument in the magnetic meridian, and set the scale a mètre away, the centre of the scale being opposite to the mirror and parallel to it. Raise the galvanometer or scale, and bend the aluminium support of the needle slightly, if necessary, until the reflection from the mirror falls on the scale. Focus by means of the lens until a distinct image of the wire is obtained in the middle of the image of the hole upon the scale. Bring this image to the middle of the

scale by turning the directing magnet. The instrument will now be ready for use.

49. *Use of Box of Coils.*—It is necessary in many experiments to have the means of varying by degrees the amount of resistance in a galvanic circuit. A box of coils arranged in series is generally used for this purpose whenever the requisite variation is capable of being made by steps, none of which are less than a unit of resistance. Fig. 64 exhibits the interior of such a box of coils as usually

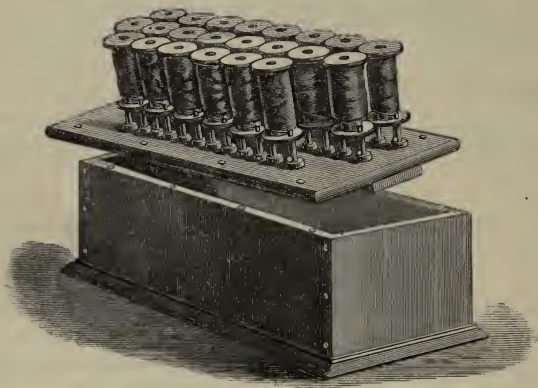


Fig. 64.—INTERIOR OF BOX OF COILS.

arranged, so as to serve the double purpose of a resistance box and a Wheatstone's bridge. In the present lesson it is only required for the former purpose. A plan of the arrangement of the coils is seen in Fig. 65. On a block of ebonite *abcd* there are mounted a good many thick brass connecting pieces distributed in three rows, somewhat in the shape of the letter S. The parts AB, BC are known as the *Proportional Arms.* These are connected with the *Rheostat Arms* DEF by means of a brass piece CD, movable at pleasure by unscrewing its

clamp screws at C and D. At A, B, C, D, E and F are binding screws. Between each of the brass pieces there is a space into which a well-fitting brass plug or stopper may be placed so as to make perfect metallic contact from the one piece to the other. The plugs may be inserted or removed at pleasure, being provided with an ebonite handle for the purpose. The holes and plugs are all exactly similar, so that any plug would fit any hole. On

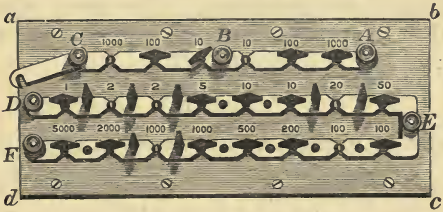


Fig. 65.—PLAN OF BOX OF COILS.

the inside of the ebonite lid there are bobbins for holding the wire. Each bobbin consists of a brass tube covered with a layer of paper. It is provided at each end with an ebonite disc. The bobbin is kept in position by two screws which pass through the lower ebonite disc. These screws are each in connection with the wire of the bobbin below and with the corresponding brass segment on the upper side of the ebonite lid; but they may be separated from the latter if necessary by unfastening two small screws. Usually, however, the screw joints at these points are soldered in order to render the contact more secure.

The wire employed for these resistances is of German silver,[1] selected both on account of its high resistance and the small variation of this due to change of temperature. The wire is covered with one or two layers of white silk.

[1] German silver is an alloy of 50 to 60 parts of copper, 25 to 30 parts of zinc, and 15 to 20 parts of nickel.

In winding the wire is doubled upon itself, and then wound so doubled. This method is adopted in order to avoid *self-induction*, and also to avoid any *electro-magnetic* effect which might vitiate the galvanometer readings. For the lower resistances thick wires are employed, in order that a great length of wire may be obtained, and thus a more exact adjustment secured. Furthermore, the lower resistances may be subjected to greater heat than the higher resistances. The actual sizes of the wires used in the rheostat arm are exhibited in the following table :—

TABLE E.

SERIES OF WIRES SUITABLE FOR RESISTANCE COILS.

Ohms.	Diameter of Wire in Inches.	Ohms.	Diameter of Wire in Inches.
1	·05	100	·020
2	·05	200	·013
5	·04	500	·013
10	·031	1000	·008
20	·031	2000	·008
50	·022	5000	·005

The resistances of the various proportional arms are 10, 100, 1000, the sizes of wire as given above being used for these resistances.

The student will understand that a set of standard resistances plays in the measurements of resistance the same part that a set of standard masses plays in the measurements of mass.

50. *Care and Use of the Box of Coils.*—The success of some of the subsequent measurements will depend largely upon the observance of the following precautions: (1.) The ebonite should be free from dust, etc., especially in the intervals between the brass pieces. A little paraffin oil should be rubbed over the surface when it is cleaned. (2.) The plugs should be bright and free from grease. They must

be made so as to fit well into their places, and they should be tightened by means of a screw motion. Occasionally they may be just touched with the finest emery paper, but this should be done as seldom as possible, for otherwise the plugs may become loose in their holes. (3.) The connecting pieces and the surfaces of the connecting screws should be bright and clean, and the screws should be firmly screwed in their places. It is hardly necessary to remind the student that when a plug is inserted into its hole between two brass segments, the result is that the current virtually passes through these segments and through the plug, which present very small resistance, and not sensibly through the bobbin which is underneath. When, however, the plug is withdrawn, the current must all pass through the bobbin.

51. *The Rheostat.*—It will be seen that the box of coils only allows us to vary the resistance of a circuit by jumps or successive steps, but often we wish to have a very gradual variation. This is accomplished by means of the rheostat, of which Fig. 66 shows a simple and satisfactory form. Two

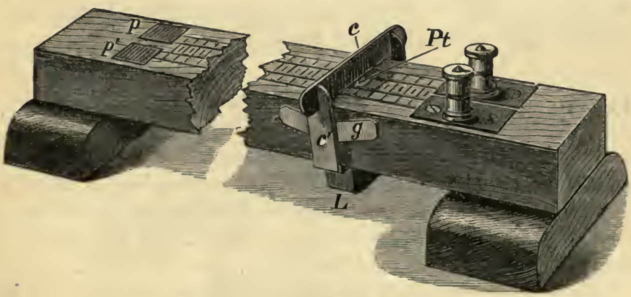


Fig. 66.—Straight Wire Rheostat.

German-silver wires are laid side by side on a long graduated board. The ends terminate in metal plates, to which they are soldered. Two of the plates are seen at p and p', and the other two are seen provided with binding screws. To

connect the two wires a movable metal contact piece c is used. This has its lower edge (Pt) covered with a piece of platinum foil. The contact piece is supported by two side strips (one is seen at c'), and is made to press firmly on the wires owing to the weight of a block of lead L that is held by the side pieces. To prevent a lateral motion two guide arms are provided, of which g is one. In use the instrument is included in the circuit and the contact piece moved until the desired resistance is obtained.

52. *Figure of Merit.*—In order to express the sensibility of a galvanometer in measurable terms, it is usual to determine the current in **ampères** which will be required to produce a deflection on the scale of one division.

The current required is called the *Figure of Merit.* This current, and therefore the figure of merit, will depend upon the position of the directing magnet, and also upon the distance of the scale from the galvanometer. It is desirable that the scale should be kept at a fixed distance from the galvanometer, so that it is the position of the directing magnet that will have to be raised or lowered in order to obtain the required sensibility.

LESSON XXIII.—Figure of Merit of Galvanometer.

53. *Apparatus.*—A mirror galvanometer and its accessories, a box of coils, a Daniell's cell, a plug key (Fig. 67).

Method.—For the purpose of this lesson it will be necessary to obtain approximate values of the resistance of the battery and of the galvanometer.

Resistance of the Galvanometer.—Make connections as in Fig. 68, where B is the battery, K a plug key, G the galvanometer, R the box of coils, and S a shunt, or, in other words, a short piece of wire placed so as to *short-circuit* the battery at pleasure. When the shunt is of sufficiently small resistance, the deflection of the galvanometer may be reduced

to a readable amount. Furthermore, the *combined resistance* of the battery and shunt will be so small, that in comparison with that of the rest of the circuit it may be neglected. If

Fig. 67.—Plug Key.

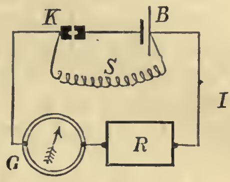


Fig. 68.

now resistance be introduced into the lower part of the circuit by taking plugs out of the resistance box until the original deflection is halved, we shall know that the total resistance has been doubled, so that the added resistance must be equal to that of the galvanometer.

Resistance of the Battery.—To determine this the same principle is applied, only the shunt is now transferred (Fig. 69) to the galvanometer. Here the resistance of the galvanometer being very great compared to that of the shunt, the great body of the current will go through the circuit and shunt, and only a very small portion of it through the galvanometer. The intensity of the current will therefore be virtually regulated by the resistance of the main circuit, and this intensity will of course be recorded by the galvanometer. Thus by this arrangement the galvanometer records the strength of the current, but does not sensibly interfere with it. Now let us introduce, by means of the box of coils, resistance until the deflection of the galvanometer is halved; this means that the current is halved, and that the resistance of the whole circuit is doubled. Hence the additional resistance introduced must be equal to that of the battery, as the joint resistance of shunt and galvanometer is negligible.

In making these tests, if the battery should vary, the

results will be affected. It is therefore important to make the tests quickly, and the battery circuit should only remain closed while the tests are being made. More especially is this true when the battery is short-circuited, for it is a rule that the smaller the resistance of the circuit the more liable is the battery to be inconstant.

Figure of Merit.—Make connections as in Fig. 70. Employ resistances so as to give successively deflections of about 150, 100, and 50 divisions.

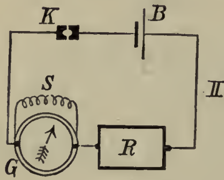


Fig. 69.

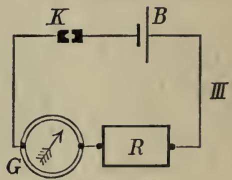


Fig. 70.

Divide the electromotive power of the battery in volts (a Daniell's cell with E. M. F. = 1·08 volt approximately) by the total resistance in ohms of the circuit. This will give the current in ampères, which, when divided by the deflection, will give the figure of merit required.

Example—Resistance of Galvanometer.—To reduce deflection from 240 to 120 divisions, 9 ohms were required, which is the resistance of the galvanometer.

Resistance of Battery.—To reduce from 220 to 110, 3 ohms were required.

Figure of Merit.—

R = Total Resistance.	D = Deflection.	Figure of Merit = $\frac{1 \cdot 08}{DR}$.
2962	150	·00000243
4342	100	·00000248
8652	50	·00000249

Mean ·00000247 ampère,
or 2·47 microampères.

The directing magnet had its north pole to north, and was placed at the top of the support.

54. *Determination of E. M. F.*—Unless we are provided with standards of E. M. F., it will be difficult to determine the E. M. F. of a cell in volts. No official standard has been yet issued. The best available is a cell of Latimer Clark's construction.

LESSON XXIV.—Comparison of Electromotive Forces by the High Resistance Method.

55. *Exercise.*—To compare together the electromotive force of various cells.

Apparatus.—A coil of high resistance—at least 5000 ohms, a mirror galvanometer and its accessories.

Method.—This consists simply in observing the deflections produced when the high resistance is in circuit.

Theory of the Method.—Let E_1 be the electromotive force of one of the cells (say a Daniell's cell), and E_2 that of another cell (say one of Bunsen's). Also let B_1 and B_2 be the respective resistances of these cells, while R is the resistance of the external circuit, including the galvanometer. When the Daniell's cell is in circuit we shall have, by Ohm's law,

$$C_1 = \frac{E_1}{B_1 + R},$$

and when the Bunsen's cell is in circuit we shall have

$$C_2 = \frac{E_2}{B_2 + R};$$

hence

$$C_1 : C_2 :: \frac{E_1}{B_1 + R} : \frac{E_2}{B_2 + R} \quad . \quad . \quad . \quad . \quad (1)$$

Now if R be very great compared to B_1 or B_2, this proportion will virtually become (since $B_1 + R$ is sensibly the same as $B_2 + R$)

$$C_1 : C_2 :: E_1 : E_2 . \quad . \quad . \quad . \quad . \quad (2)$$

In other words, the electromotive forces are to one another in the same proportion as the currents, that is to say, in the same proportion as the deflections produced.

The higher the resistance R, the more accurate will be this method. To obtain an idea of the error produced let us imagine that the observed deflections are 100 and 200 divisions. This will, according to formula (2), also be the ratios between the electromotive forces. But if the resistance of the batteries be respectively 5 ohms and 0·5 ohm, and R be = 5000 ohms, we shall have by formula (1)

$$E_1 : E_2 :: \frac{100}{5005} : \frac{200}{5000{\cdot}5} :: 500050 : 1001000 :: 1 : 2{\cdot}002,$$

or almost exactly the same as before.

Example.—Standard cell (E. M. F. = 1·46 volt) gave 190 divisions of deflection through 20,000 ohms. With the same resistance the results with other cells were

Daniell, 148 divisions, hence E. M. F. $= \frac{1{\cdot}46 \times 148}{190} = 1{\cdot}14$ volts

Bichromate, 260 „ „ „ $= \frac{1{\cdot}46 \times 260}{190} = 2{\cdot}00$ „

Lesson XXV.—Proof of Ohm's Law.

56. *Apparatus.*—A mirror galvanometer; a coil of very fine German-silver wire at least 5000 ohms in resistance; two small plates of copper having binding screws soldered to them, and fixed to a board so that their inner edges are just a mètre apart; a thin German-silver wire, which is stretched tight along the board and soldered to the copper plates; a key or commutator; a few cells of a constant battery will likewise be required.

Method.—Make connections as shown in Fig. 71, in which B is the battery, K the key, G the galvanometer, R the high resistance, PQ the German-silver wire. The unconnected end of the wire leading from the high

resistance should be filed into a wedge shape, and then thrust through a cork, which is intended to serve as a handle and prevent the temperature of the observer's hand from affecting the wire. Observations are made in the following order: place the free end at different points along the wire, and read the deflection produced at each point; reverse the poles of the battery, and then repeat the observations in the opposite order. The two results may be somewhat different, owing to possible variation in the strength of the current. The mean should therefore be taken.

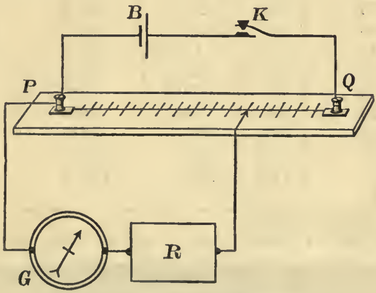


Fig. 71.—Proof of Ohm's Law.

Now if the differences of potential or electromotive force along the wire are, as Ohm's law would indicate, proportional to the resistances, that is to say, to the length of wire between the two points at which the potential is taken or tapped, it follows that the number expressing this resistance should have a constant ratio to that expressing the difference of potential. But the difference of potential will be expressed by the current of the galvanometer which it produces, so that ultimately this current will be proportional to the distance between P and the free end of the galvanometer wire.

That this proportion holds fairly well will be seen from the following series of experiments. But before exhibiting

this series we would remark that the galvanometer circuit is to be here regarded as one which taps the main circuit above the wire and indicates the difference in potential by means of the deflection produced, without sensibly interfering with this main current.

Example.—

Reading on PQ.	Deflection.			
(1)	I.	II.	Mean (2).	$\frac{(2)}{(1)}$
10	11	12	11·5	1·150
20	24	24	24·0	1·200
30	37	35·5	36·3	1·210
40	48	47·5	47·8	1·195
50	60	59·5	59·8	1·196
60	70	70·5	70·3	1·171
70	82	82	82·0	1·171
80	94	94	94·0	1·174
90	106	106	106·0	1·178
100	118	118	118·0	1·180

The results of this lesson may best be represented

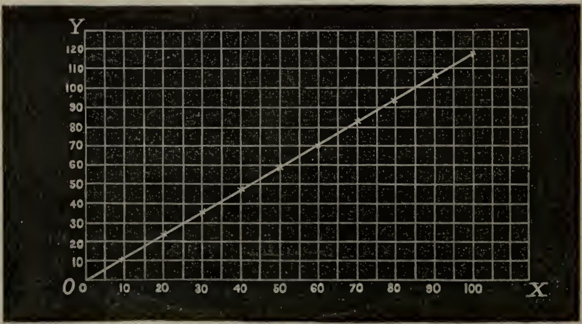


Fig. 72.

graphically. Let the line of abscissæ or horizontal line represent distances on the wire, and the line of ordinates

the observed potentials at these points. On plotting the observations we obtain a nearly straight line (Fig. 72). This shows at once that the fall of potential between two points is proportional to the resistance between these points. This method of recording results will enable the student to understand the principle of Wheatstone's Bridge.

57. *Wheatstone's Bridge.*—Suppose that OAC and O′A′C′ (Fig. 73) are two wires whose resistances are represented by

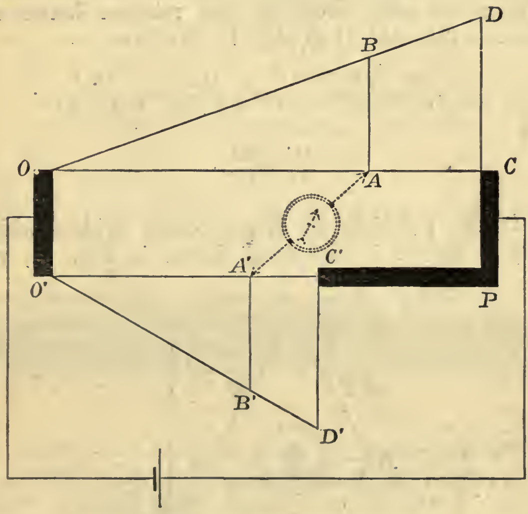


Fig. 73.—Theory of Wheatstone's Bridge.

their lengths. Let their ends be connected by thick copper pieces, OO′ and CPC′, of which the resistances may be neglected. We shall suppose that a battery is connected with OO′ and CPC′, whereby these parts are kept at a constant difference of potential, represented by the equal lines CD and C′D′ (the potential at OO′ being supposed for

convenience equal to zero). The fall of potential along the wires will be given by OBD and O′B′D′. Take any point A in OC and find the potential at this point by erecting an ordinate AB. Now a corresponding point A′ can be formed along O′C′, such that the potential A′B′ at this point shall be equal to AB. In this case a galvanometer connecting A and A′ would not indicate any current, since these points being at equal potentials no current would pass from the one to the other through the galvanometer. But under these circumstances what must be the relation between the resistances OA, AC, O′A′, A′C′? We have

$$\frac{OA}{OC}=\frac{AB}{CD}=\frac{A'B'}{C'D'}=\frac{O'A'}{O'C'}, \text{ or } \frac{OA}{OA+AC}=\frac{O'A'}{O'A'+A'C'};$$

hence

$$\frac{OA}{AC}=\frac{O'A'}{A'C'}.$$

This is the principle of Wheatstone's Bridge, which is usually arranged in the form shown in Fig. 74, where

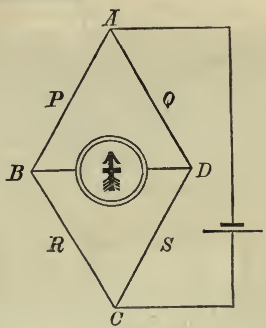


Fig. 74.

P, Q, R, S are four resistances. If these be in the ratio $\frac{P}{Q}=\frac{R}{S}$, then the galvanometer will not be affected. When

this adjustment is made any one of the four resistances may be determined if the other three are known.

Lesson XXVI.—The Wheatstone's Bridge.

58. *Apparatus.*—A mirror galvanometer with its accessories. A slide half-mètre Wheatstone's bridge, or the following materials for its manufacture: (1.) Board of varnished wood 2 feet long, 4 inches broad, $\frac{3}{4}$ inch thick. (2.) Some sheet copper $\frac{1}{16}$ inch thick. (3.) Seven telegraphic binding screws. (4.) Uncovered German-silver wire, 2 feet long, No. 28 S.W.G. (5.) A half-mètre boxwood scale $\frac{1}{2}$ inch broad and $\frac{1}{8}$ inch thick. This should be divided along one edge into half centimètres. (6.) Sixteen $\frac{1}{4}$ inch brass screws. (7.) Two small pieces of copper, $\frac{1}{2}$ inch square, $\frac{1}{10}$ inch thick.

Method of Manufacture.—The completed bridge is shown in Fig. 75. At CDE and FGH are L-shaped pieces of

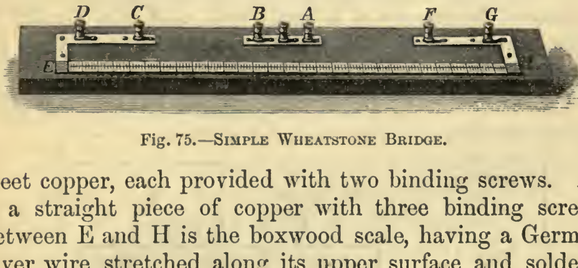


Fig. 75.—Simple Wheatstone Bridge.

sheet copper, each provided with two binding screws. AB is a straight piece of copper with three binding screws. Between E and H is the boxwood scale, having a German-silver wire stretched along its upper surface and soldered to the copper at E and H. In making the bridge—(1.) The copper strips should be cut out. Fig. 76 shows their shapes and dimensions. They will require to be drilled with holes just large enough to receive the shank of a binding screw at the places marked with large circles; also with smaller holes at the places shown, in order to receive the screws for fastening the coppers to

the board. (2.) The boxwood scale must be screwed down in the position shown in Fig. 75, the heads of the screws being screwed below the surface of the scale. (3.) The binding screws must be soldered to the copper straps. This operation may be performed without a soldering iron, the strips being heated in a Bunsen's flame. Also at the shaded portion of the L-shaped pieces a square piece of copper must be soldered, in order that the level of the copper may be brought up to the level of the scale. (4.) Bore holes in the wood to admit the shanks of the binding screws, then fasten the copper strips down by means of the screws. (5.) One end of about 2 feet of the German-silver wire, which must not have an insulating covering,[1] is to be soldered to E, then, the other end being held by an assistant, the wire must be stretched straight along the scale and then soldered at H. The soldering should be performed by means of a small iron, and care should be taken that the wire is in metallic communication with the coppers at the ends of the scale.

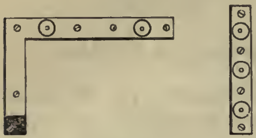


Fig. 76.

The Bridge Connections.—Fig. 77 shows the necessary

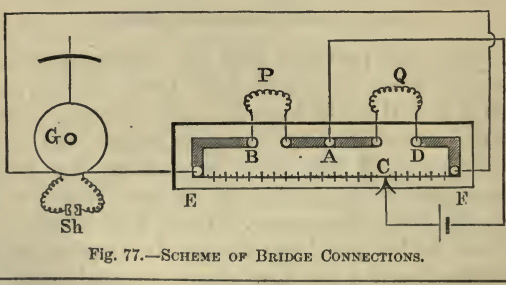


Fig. 77.—Scheme of Bridge Connections.

[1] To remove silk from a wire without injury to the wire, it should be boiled in a strong solution of caustic soda.

arrangement for comparisons of resistance. Here the letters correspond with those of Fig. 74, which should be first drawn by the student, in order to help him in making his connections. It will be noticed that in the arrangement used in practice R and S are varied at will by sliding the battery terminal along the German-silver wire. To do this more conveniently the battery terminal is thrust through a cork at C, and the end of the wire is filed into a wedge-shaped form. A portion of the cork may be cut away if necessary, so that it may be held against the edge of the base board as it is moved along. The galvanometer (G) should be provided with a simple shunt (Sh) for lessening its sensibility at will.

Operations with the Bridge.—(1.) Measure 8 feet (*i.e.* four times the length of the base board) of No. 36 S.W.G. silk-covered copper wire. Make it into a doubly wound spiral, and connect its bared ends across the gap P of the bridge. Make a second spiral in exactly the same manner, and connect it across the gap Q. Shunt the galvanometer, and touch the end F of the bridge with the free battery terminal, the galvanometer will be deflected, say, to the right; now touch the end E and the deflection should be to the left. This will show that the connections are correct, that the contacts at P and Q are good, and that neither of the spirals is broken. Find roughly the position at which the galvanometer shows no deflection, then remove the shunt and obtain the position of equilibrium more accurately. Call the position of equilibrium a, then, since the bridge may be considered to be divided into 1000 parts, we shall have

$$\frac{P}{Q}=\frac{a}{1000-a}.$$

Example.—The bridge reading is 499, hence

$$\frac{P}{Q}=\frac{499}{1000-499}=\frac{499}{501}=\frac{1}{1\cdot004},$$

or P is very nearly equal to Q.

(2.) Make a third spiral of 8 feet of No. 36, place it in the same screw holes as the spiral at P, so that the two spirals are in *multiple arc*. Now compare the two resistances.

Example.—

$$a=331 \qquad 1000-a=669$$

$$\frac{P}{Q}=\frac{331}{669}=\frac{1}{2 \cdot 02}$$

or the wires in multiple arc have only half the resistance of the single wire.

(3.) Place the two spirals at P in *series* by connecting their ends by small clamps, and again compare the resistances.

Example.—

$$a=668 \qquad 1000-a=332$$

$$\frac{P}{Q}=\frac{668}{332}=2 \cdot 01$$

showing that the effect of doubling the length of the wire is to double the resistance.

(4.) Take 8 feet of No. 28 S.W.G. copper wire for Q and balance it against 8 feet of No. 36 for P. Find the average diameter of both wires as exactly as possible by the micrometer-calliper.

Example.—

$$a=819 \qquad 1000-a=181$$

$$\frac{P}{Q}=\frac{819}{181}=4 \cdot 52$$

Diameters—No. 28 = ·015 inch ; No. 36 = ·007 inch.

$$\frac{\text{Square of diameter, No. 28}}{\text{Square of diameter, No. 36}}=\frac{\cdot 000225}{\cdot 000049}=4 \cdot 59,$$

from which we see that the resistance varies inversely as the square of the diameter.

(5.) Compare the resistance of one spiral of No. 28 at P and the other at Q *in multiple arc* with the spiral of No. 36.

Example.— $\frac{P}{Q}=1{\cdot}221.$

Now we have previously found that the spiral of No. 36 wire had a resistance of 4·52, calling that of the spiral of No. 28 unity. What then will be the resistance of the spirals in multiple arc? This is found by aid of the following rule:—*The resistance of wires in multiple arc is equal to the reciprocal of the sum of the reciprocals of the respective resistances.* Thus in the above case the resistance of Q will be

$$\frac{1}{1+\frac{1}{4{\cdot}52}}=\frac{1}{1{\cdot}221}.$$

(6.) Calibrate a rheostat, such as that of Fig. 66.

Lesson XXVII.—Manufacture of a One-Ohm Coil.

59. *Apparatus.*—The same as before, with the addition of some silk-covered German-silver wire, No. 28 S.W.G.; materials for mounting the coil, and a standard ohm.

Method.—Cut off one mètre length of the wire and measure its resistance, then calculate what should be the length to give one ohm resistance. From the total length cut off a piece rather greater than the calculated length, and proceed to mount it with attached terminals for future use. The methods of mounting that might be adopted are very various. In Fig. 78 we have one of the simplest of these. Here *ab* is a flat piece of hard wood, notched along its two edges. The wire is wound between the notches, and the ends are soldered to two copper strips *c* and *c′*. Each copper strip must have a small hole *h* through which the German-silver wire may be passed before it is ultimately soldered to the copper; also a hole for a screw *s* for securing the copper to the wood, and a notch *n* which fits the binding screw of the bridge. Ribbon or tape is wound

outside the wire for protection, its ends being secured by small tacks. The wire having been mounted must have its resistance tested; if this should be found to be rather too great the wire should be unsoldered at one end, drawn

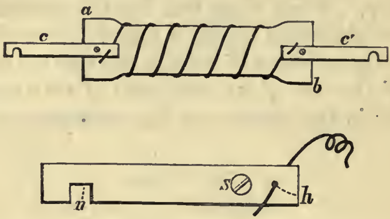


Fig. 78.—The One-Ohm Coil.

through the small hole in the copper, and again soldered. This adjustment must be repeated if necessary. It is not, however, desirable to spend much time in making an exact adjustment, but when this is sufficiently good the resistance should be measured as exactly as possible, and its value recorded on the wood.

Example.—One mètre of the wire gave against the standard ohm a balance on the bridge at 52, hence its resistance was $\frac{520}{1000-520} = 1{\cdot}083$ ohm. Hence the length of 1 ohm in millimètres will be $\frac{1000 \times 1}{1{\cdot}083} = 923$ millimètres. A piece 925 mm. was cut off and mounted, as described; its resistance was found rather too great. On reducing the length about 1·5 mm. it was found to be almost an ohm.

Lesson XXVIII.—Calibration of Galvanoscope.

60. *Apparatus.*—That of Lessons XXIII., XXIV., and XXVI.; also a Bunsen's or a Grove's cell.

Method.—(1.) Charge the cell and compare its E. M. F. with that of a standard cell by Lesson XXIV. (2.) Measure

the resistance of the galvanoscope by Lesson XXVI. (3.) Measure the internal resistance of the cell by Lesson XXIII. (4.) Connect the cell, box of coils, and galvanoscope in series, and take readings of the latter with different resistances in the circuit. (5.) Calculate the current in ampères producing the different deflections. Draw a table up for use with the instrument; also plot a curve showing the relation between the currents and deflections.

Example.—A vertical galvanoscope was calibrated.

E. M. F. of cell = 1·87 volt.
Resistance of cell = ·25 ohm, nearly.
Resistance of galvanoscope = 9·75 ohms.

If R be the resistance from box of coils, then the current C in ampères will be $C = \frac{1 \cdot 87}{R + \cdot 25 + 9 \cdot 75}$, from which was calculated the following table:—

R.	C.	Deflection.
0	·187	75
1	·170	73
3	·144	69
5	·125	65
10	·0935	58
15	·0748	51
20	·0623	45
30	·0467	37
50	·0311	25
100	·0170	13
200	·0089	7

The curve plotted from these numbers was regular.

CHAPTER IV.

THE TANGENT GALVANOMETER.

61. WHEN the measurements that we require to obtain do not need a sensitive galvanometer, it is often convenient to use the **tangent galvanometer.** In order to understand thoroughly the principle of the instrument it will be desirable to make, by means of such an instrument, a number of experiments.

LESSON XXIX.—Proof of Law of Tangents.

62. *Apparatus.*—(1.) A hoop provided with a single turn of thick wire and a number of turns of fine wire. The woodwork of the hoop should be cut away in one place to allow of the number of turns to be counted and the mean radius of the coil to be ascertained.

The hoop (Fig. 79) is mounted on a base provided with two uprights, upon which the deflection magnetometer of Lesson XIV. may be fixed so that it may slide to or from the hoop. (2.) A box of coils, constant battery, a commutator, and connecting wires.

Experiment I.—To Verify the Law of Tangents.—Arrange the battery with the commutator, the box of coils and the galvanometer being placed in series (see Fig. 80). The battery used should be one of low resistance and of great constancy, like a Bunsen's. We shall assume either that its resistance is so low as to be negligible, or that it has

been measured by the method of Lesson XXIII. It will be taken for granted also that the resistance of the thin

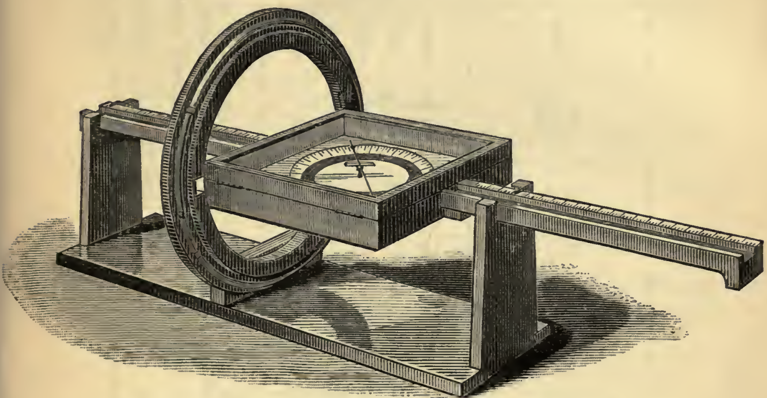


Fig. 79.—TANGENT GALVANOMETER WITH SLIDING COMPASS BOX.

wire galvanometer coil has previously been ascertained by means of the Wheatstone's bridge.

Place the coil of the instrument in the magnetic meridian. This should be the case when the pointer is at zero. Change the resistance in the circuit until the deflection caused by putting on the current is about 60°. Read both ends of the needle, reverse the current, and again read the ends of the needle. Take more plugs out of the resistance box, so as to reduce the deflection. Repeat the readings. Again increase the resistance, and proceed as before. Do this several times. Arrange and calculate your results as in the following example :—

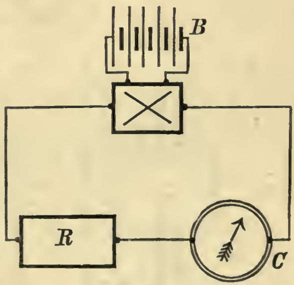


Fig. 80.

Example.—

Total Resistance in Ohms. R	Readings.				Mean.	Tangents.	Logs of R.	Logs of $\frac{1}{R}$.	$\frac{1}{R}$	Log Tangents.	(3) + (6)	$\frac{E}{K}$
	A Position of Commutator.		B Position of Commutator.									
	E. End of Needle.	W. End of Needle.	E. End of Needle.	W. End of Needle.								
(1.)					° ° ′	(2.)	(3.)	(4.)	(5.)	(6.)		
17·57	67·8	67·4	70·2	70·9	69·1 = 69 6	2·6187	1·2447	$\bar{2}$·7553	·05691	10·4181	·6628	4·601
37·57	50·2	50·0	52·2	52·9	51·3 = 51 18	1·2482	1·5748	$\bar{2}$·4252	·02662	10·0963	·6711	4·689
57·57	38·1	37·9	39·2	39·8	38·2 = 38 12	·7869	1·7602	$\bar{2}$·2398	·01737	9·8959	·6561	4·530
67·57	34·0	33·8	35·0	35·1	34·5 = 34 30	·6873	1·8298	$\bar{2}$·1702	·01480	9·8371	·6669	4·644
117·57	21·4	21·2	21·5	21·9	21·5 = 21 30	·3939	2·0705	$\bar{3}$·9295	·008502	9·5954	·6659	4·634

Notes.—(1.) For ease in looking out the tangents in the table we have given degrees and minutes obtained by multiplying the decimal part by 60. (2.) Column (3) gives the logs of numbers in column (1). To find $\frac{1}{R}$ we must remember that the decimal part of the logarithm should always be positive. Thus $\log \frac{1}{17{\cdot}57} = -\log 17{\cdot}57 = -1{\cdot}2447 = \bar{2} + 1 - {\cdot}2447 = \bar{2}{\cdot}7553$. (3.) To logs of tangents in column (6) 10 has been added to avoid negative characteristics; this must be subtracted when adding columns (3) and (6).

Explanation.—We wish to prove the following relation—

Current = constant quantity, depending upon the size of hoop and the number of the coils multiplied by the tangent of the angle of deflection,

or using letters—

$$C = K \tan \alpha \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where C is the current, K is the constant, and α the angle of deflection.

Now, according to Ohm's law,

$$C = \frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E is the E. M. F. of the battery used, which may be supposed to remain constant, and R the total resistance in the circuit. From (1) and (2)

$$R \tan \alpha = \frac{E}{K} = \text{constant}.$$

Thus if (1) is correct, we ought to find that the resistance of the circuit multiplied by the tangent of the angle of deflection remains a constant quantity. In the previous example this is seen to be the case within the limits of error of the experiment.

Use of Graphical Method.—We see from (1) and (2) that $\tan \alpha$ ought to vary inversely with R. If this is true, by plotting $\tan \alpha$ with reference to $\frac{1}{R}$ a straight line should be obtained, as in the analogous case of Lesson XXV. In the previous example the values of $\tan \alpha$ and of $\frac{1}{R}$ have been given to facilitate the use of the graphical method.

Lesson XXX.—Proof of Law of Distance.

63. *Exercise.*—To prove experimentally the law relating to the action of the galvanometer coil on the magnetic needle at different distances.

Apparatus.—As before.

Method.—Take deflections with the compass box at different distances from the coil, reading off the distances by help of the pointers on the ends of the uprights and the scales on the arms. Take readings on both sides of the hoop, with the commutator in its two positions, in each case reading both ends of the needle. Measure the mean radius of the coil, and finally compare the tangents of the mean deflections with values derived by calculation from the formula [1]—

$$K\frac{a^2}{(a^2+x^2)^{\frac{3}{2}}}=\tan\alpha,$$

where a is the radius of the hoop and x the distance of hoop from centre of magnetic needle.

Example.—$a = 3{\cdot}75$ inches.

(1.) Distance from centre of compass needle to centre of coil or x.	(2.) Mean deflection.	(3.) Tangent of deflection.	(4.) Value of $\frac{a^2}{(a^2+x^2)^{\frac{3}{2}}}$	(5.) 3÷4	(6.) Adopted value of $K\frac{a^2}{(a^2+x^2)^{\frac{3}{2}}}$
inches.	°				
·0	40	·8391	·2667	3·147	·8391
1·0	37	·7536	·2406	3·132	·7570
1·5	34	·6745	·2135	3·160	·6716
2·0	30·75	·5949	·1832	3·247	·5766
2·5	26·75	·5040	·1536	3·281	·4834
3·0	22·25	·4091	·1270	3·221	·3995
3·5	18·5	·3346	·1042	3·210	·3278
4·0	15·375	·2750	·08532	3·222	·2685
4·5	12·75	·2263	·06996	3·234	·2192
5·0	10·5	·1853	·05760	3·218	·1812
5·5	8·875	·1561	·04767	3·275	·1500
6·0	7·5	·1317	·03970	3·242	·1249

On dividing the numbers [2] in the third column by the

[1] For the proof of this see vol. ii. p. 319 of our larger work (*Elementary Practical Physics*).

[2] The columns with logarithms have been omitted.

numbers in the fourth the quotient should be constant,

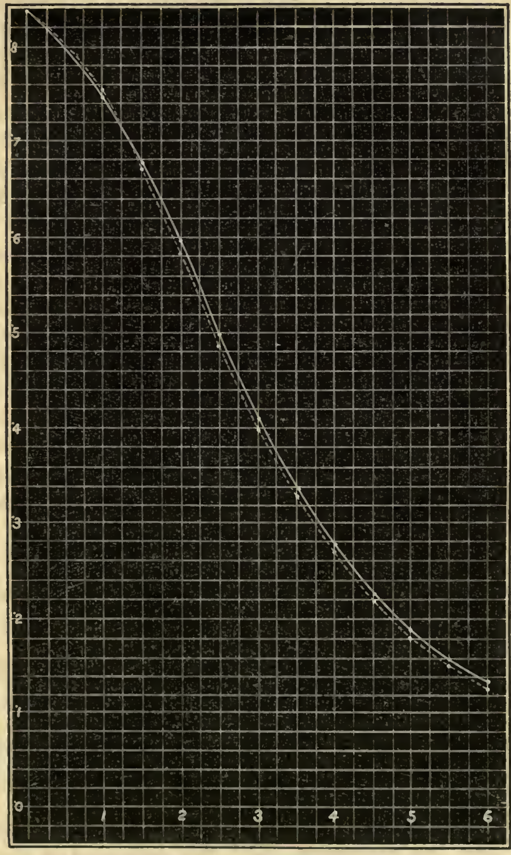


Fig. 81.—Graphical Proof of Law.

as we see it is from (5), at least within the errors of observation. In experiments of this kind, where the degree

of accuracy is not high, the law is best tested by the use of the graphical method—that is, by plotting two curves and comparing their form. The continuous line of Fig. 81 shows the result of taking the numbers in the first column as abscissæ and those in the third column as ordinates, thereby giving a curve showing the relation obtained by experiment. In order to make a curve showing the theoretical relation comparable with that due to experiment, some value must be given to K which will bring the numbers in the fourth column near those in the third column. If we wished the two curves to fall upon each other, the best value to give to K would be the mean of the constants in the fifth column. We have selected the value 3·147, which will enable us to distinguish without confusion the two curves, the theoretical one being a dotted line. On multiplying the numbers of the fourth column by 3·147 the numbers of the sixth column are obtained, which give the required ordinates of the theoretical curve.

It will be noticed that the two curves are very like each other, thereby giving us reason to conclude that the theoretical formula is right.

Lesson XXXI.—Determination of Constants of Tangent Galvanometer.

64. *Exercise.*—To find the constant of the tangent galvanometer by calculation and by experiment.

Apparatus.—The depositing cell of Lesson XX., with accompanying liquids, etc.; a Daniell's battery; box of coils; commutator; chemical balance; stop-watch; the galvanometer whose constant is required.

Experimental Method.—Adjust the number of cells in the battery and the resistance until the deflection of the galvanometer is not greater than 60°, the connections being as in Fig. 82, where D is the depositing cell. Next thoroughly clean the anode and the working cathode—dry

them in a current of hot air and weigh them to within half a milligramme. Now fix them in their position in the depositing cell, the circuit being still incomplete. Set the stop-watch to an exact hour, and then simultaneously start the current and the watch. Read the galvanometer, rapidly reverse the commutator so as not to lose time, and read again. Take readings from time to time and adjust the resistance

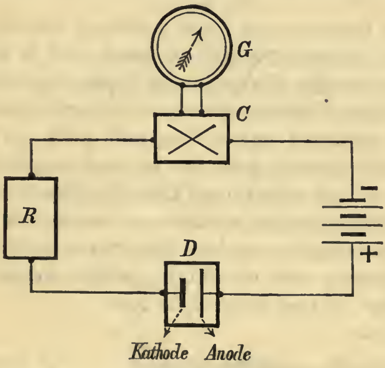


Fig. 82.

in circuit if the deflection does not keep constant. The deposition should be continued for some time, at least two hours, and at the end of the time the current should be discontinued, and the watch stopped. Remove the cathode, wash it well first in common water and then in distilled water, dry it in a current of hot air and weigh it. From the gain in weight in the observed time calculate the average current that has been circulating. This having been determined, deduce the constant of the galvanometer from the formula

$$K=\frac{C}{\tan\alpha},$$

where α is the average deflection.

To find C we apply the rule:—An ampère of current will deposit ·000326 grm. of copper per second.

Precautions.—The battery chosen for this purpose should be a constant one. When the constant to be determined is small, Daniell's may be employed. The Daniell's battery should be left short-circuited through a resistance some time before use, so that it may be in a normal working condition.

If it be necessary to have a strong current, a Grove's or Bunsen's battery should be used, and it will then be necessary to employ plates in the depositing cell of a large size; for when a certain *density* of current (that is to say, number of units of current to unit area of electrode) is exceeded the deposit is in the form of a powder and does not adhere. It is ascertained that the loss of weight of the anode cannot be used as an accurate measure of the current, owing to secondary corrosive chemical action and disintegration producing loss of weight, which would vitiate the determination of real electrolyte loss.

Example.—

Weight of cathode at commencement . .	10·425 grms.
,, ,, at end	11·219 ,,
Gain in weight . . .	·794

Mean deflection 47°. Tan 47° = 1·0724. Time 125 minutes.

$$\text{Hence weight of copper in grammes per second} = \frac{\cdot794}{60 \times 125}.$$

$$\text{Strength of current in ampères} = \frac{\cdot794}{60 \times 125 \times \cdot000326}.$$

$$\text{Constant of galvanometer} = \frac{\cdot794}{60 \times 125 \times \cdot000326 \times 1\cdot0724} = \cdot3028.$$

Method by Calculation.—The complete formula for the tangent galvanometer is [1]—

$$C = \frac{H(a^2+x^2)^{\frac{3}{2}}}{2n\pi a^2} \tan \alpha,$$

[1] See *Elementary Practical Physics*, vol. ii. p. 321.

where C is the strength of current, H the horizontal component of the earth's magnetism, n the number of turns in the coil, and the other letters have their previous signification.

If $x = 0$, that is to say, when the compass needle lies in the plane of the coil, then the formula becomes—

$$C = \frac{Ha}{2n\pi} \tan \alpha.$$

To find H we proceed by the method of Lesson XVI. The deflections are first taken with the compass box on the instrument, and then the vibration box is substituted.

The value of K obtained by the above formulæ should agree with that obtained by copper deposition. It must, however, be remembered that if the measurements have been in C.G.S. units, it will be necessary to multiply the result by 10 in order that it may compare with the constant for ampères (see p. 142).

Lesson XXXII.—Determination of Resistance and E. M. F.

65. *Apparatus.*—Tangent galvanometer, commutator, box of coils, a Daniell's and a Bunsen's cell, and connecting wires.

Exercise.—To find the resistances of the two cells.

Theory of the Method.—Let the battery to be tested, along with its commutator, the galvanometer, and the box of resistance coils, be placed in series (see Fig. 80).

Let E = Electromotive force of the battery,
B = Resistance of battery,
G = Resistance of galvanometer and connecting wires,
R = Resistance of the coils,
α = Angle of deflection,

then, from Ohm's law, the current C passing through the galvanometer will be

$$C=\frac{E}{B+G+R} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

But

$$C=K \tan \alpha \quad . \quad . \quad . \quad . \quad . \quad (2)$$

by the theory of the tangent galvanometer. Hence

$$\frac{E}{B+G+R}=K \tan \alpha \quad . \quad . \quad . \quad . \quad (3)$$

Let now R be changed to R_1, causing α to be changed to α_1, then

$$\frac{E}{B+G+R_1}=K \tan \alpha_1 \quad . \quad . \quad . \quad . \quad (4)$$

Hence, dividing (3) by (4), we obtain

$$\frac{B+G+R_1}{B+G+R}=\frac{\tan \alpha}{\tan \alpha_1} \quad . \quad . \quad . \quad . \quad (5)$$

Hence

$$B=\frac{R \tan \alpha - R_1 \tan \alpha_1}{\tan \alpha_1 - \tan \alpha}-G \quad . \quad . \quad . \quad . \quad (6)$$

a general formula for the battery resistance.

The expression (6) may be simplified in approximate measurements by making $R = 0$, $\alpha_1 = 45°$, then

$$B=\frac{R_1}{\tan \alpha - 1}-G \quad . \quad . \quad . \quad . \quad (7)$$

or. still better, by making $\tan \alpha_1 = \frac{1}{2} \tan \alpha$, and then

$$B=R_1-(2R+G) \quad . \quad . \quad . \quad . \quad (8)$$

When this last formula is used the method is called the *half-deflection method.*

Practice of the Method—(1.) *The best values of* α *and* α_1.—Having completed the connection as figured above, and placed the galvanometer in the magnetic meridian with the pointer at 0°, the first consideration will necessarily be

which is the best coil of the galvanometer to use, and what is the best value of deflection to obtain. On consulting a table of tangents it will be found that the effect of making an error in the reading will be greater at the extremities of the scale than at the middle, thus

tan 10° = ·1763	tan 45° = 1·000	tan 80° = 5·671
11° = ·1944	46° = 1·0355	81° = 6·314
Difference ·0181	Difference ·0355	Difference 0·643
= 9·8 per cent	= 3·5 per cent.	= 10·7 per cent

of the whole mean effect.

We see from these examples that both small and large deflections must be avoided.

If we consult our tables more minutely we shall find that the effect of making an error is actually smallest at 45°, a result which is likewise in accordance with theory.

In testing the resistance of a battery by the method of this lesson we shall require to observe two deflections. It follows as a corollary to the result just given that these ought to be at equal distances on either side of 45°, the best part of the scale being between 30° and 60°. Hence the first deflection should not be greater than 60°. Now the less external resistance we place in the circuit, the greater will be the effect of the battery resistance on the whole current; hence if a coil of the galvanometer can be found which with $R = 0$ gives α not greater than 60°, that will be the best coil to take, provided that the battery continues constant.

Example.—Single coil used. Six yards of connecting wire = ·07 ohm. The connecting wires were carefully twisted together so that they had no direct effect upon the galvanometer. This was tested by moving the wires and ascertaining that this did not produce any movement of the needle.

The following results were obtained :—

Expt.	Resistance.	Commutator up.		Commutator down.		Mean.
		East end of needle.	West end of needle.	East end of needle.	West end of needle.	
I.	0	53·8	54	56	56	54·95
II.	1	30	30	31·2	31·1	30·57
III.	2	20	20	21	21	20·5

Here we have to make use of the formula

$$B = \frac{R \tan \alpha - R_1 \tan \alpha_1}{\tan \alpha_1 - \tan \alpha} - G,$$

also G + connecting wires = ·07.

Now from the tables we find

$$\tan 54^\circ{\cdot}95 = 1{\cdot}4255$$
$$\tan 30^\circ{\cdot}51 = {\cdot}5906$$
$$\tan 20^\circ{\cdot}50 = {\cdot}3739.$$

Hence, from Experiments I. and II.,

$$B = \frac{1 \times {\cdot}5906}{1{\cdot}4255 - {\cdot}5906} - {\cdot}07 = {\cdot}64 \text{ ohm}.$$

From Experiments I. and III.,

$$B = \frac{2 \times {\cdot}3739}{1{\cdot}4255 - {\cdot}3739} - {\cdot}07 = {\cdot}64 \text{ ohm},$$

while from Experiments II. and III.,

$$B = \frac{(2 \times {\cdot}3739) - {\cdot}5890}{{\cdot}5890 - {\cdot}3739} - {\cdot}07 = {\cdot}66 \text{ ohm},$$

which gives a mean result of ·65.

Exercise.—To compare the E. M. F. of the two cells by the "*Method of Sum and Difference.*"

Place the batteries to be compared in series, then

$$K \tan \alpha_1 = \frac{E_1 + E_2}{\epsilon} \quad . \quad . \quad . \quad . \quad (1)$$

where ϵ is the total resistance in the circuit.

Now interchange the poles of one of the batteries so as to cause E_1 and E_2 to oppose each other, and let the result be as follows :—

$$K \tan \alpha_2 = \frac{E_1 - E_2}{\epsilon} \quad . \quad . \quad . \quad . \quad (2)$$

The resistance in circuit being the same as before. From (1) and (2) we find

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{\tan \alpha_1}{\tan \alpha_2} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and from (3) we obtain

$$\frac{E_1}{E_2} = \frac{\tan \alpha_1 + \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2} \quad . \quad . \quad . \quad . \quad (4)$$

or the electromotive forces are to one another as the sum and difference of the tangents of the angles of deflection when the cells are in conjunction and opposition.

Example.—Terminals 1-4. Total resistance in circuit, 220 ohms.
Cells in conjunction. $\alpha_1 = 60 \cdot 4$, $\tan \alpha_1 = 1 \cdot 76$.
,, opposition. $\alpha_2 = 31 \cdot 0$, $\tan \alpha_2 = \cdot 6$.

$$\frac{E_1}{E_2} = \frac{1 \cdot 76 + \cdot 6}{1 \cdot 76 - \cdot 6} = \frac{2 \cdot 36}{1 \cdot 16} = 2 \cdot 03.$$

66. *Additional Exercises on the Use of the Tangent Galvanometer.*—A tangent galvanometer, whose constants are known, is of great value in the laboratory for ascertaining the current required for telegraphic instruments, for ascertaining rapidly the condition of a battery, and for the graduation of simple galvanometers. These uses will furnish the student with additional exercises, such as we give below.

(1.) Ascertain the current in ampères that will be sufficient to ring an electric bell.

(2.) Ascertain the current that a bichromate cell will give from time to time when working in short-circuit.

Example.—A bichromate cell was placed in circuit with the copper strap of a tangent galvanometer, the total external resistance being ·15 ohm. The following readings were taken :—

Time.	Deflection α.	K tan α = Ampères.	
45	36	2·96	
50	35·9	2·95	
53	35·1	2·86	
54	35	2·85	
55	34·7	2·82	K=4·074
56	34·4	2·79	
57	34	2·75	
58	33·5	2·70	
59	33	2·65	

On stirring the liquid of the cell the deflection rose to $52°·5 = 5·31$ ampères, but in ten minutes later the deflection was $25·7 = 1·96$ ampère. The bichromate cell is thus seen to be under these conditions extremely inconstant. By keeping the liquid continually stirred, or by blowing air through the cell, it became very constant.

67. *The Mirror Galvanometer a Tangent Galvanometer.*—The student may be reminded that in the case of the mirror galvanometer the tangent law applies; but as the angular deflections are small, it may be shown that the readings of the scale are proportional to the currents.[1]

[1] See *Elementary Practical Physics*, vol. ii. p. 88.

CHAPTER V.

MEASUREMENT OF RESISTANCE.

68. THIS chapter will be devoted to a description of a very convenient method of measurement of resistance that is extensively employed. It demands the use of a box of coils, a cheap form of which has been designed for this work (see Appendix B).

69. *Theory and Use of Shunts.*—To reduce at will the sensibility of the galvanometer, shunts, the use of which will be already familiar to the student, are employed. Figs. 83 and 84 show two such arrangements in frequent use, the

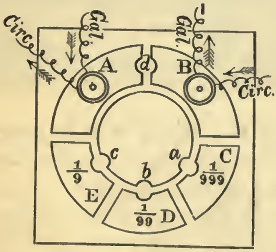


Fig. 83.
PLAN OF CIRCULAR SHUNT BOX.

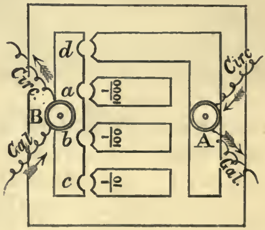


Fig. 84.
PLAN OF SQUARE SHUNT BOX.

corresponding parts in each being similarly lettered. Fig. 85 exhibits the general plan of the shunt connections.

When a plug is inserted at *d* the galvanometer is short-circuited through the thick metal portions between A and B; but when the plug is removed from *d* and inserted at *a*, *b*, or *c*, the galvanometer is shunted through one or other of the resistance coils of the shunt. The resistance that a shunt must have in order to diminish the current in any ratio may be readily ascertained. Let G be the resistance of the galvanometer and S the resistance of any shunt, while C denotes the main current which we wish to shunt. This current will divide between the galvanometer and shunt in the inverse ratio of the resistances in each; that is to say, in the ratio of S to G, and hence the current C_1 going through the galvanometer will be

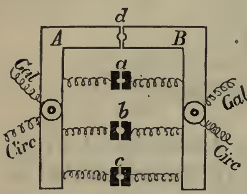


Fig. 85.—Scheme of Shunts.

$$C_1 = \frac{S}{G+S}C \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Suppose now that we wish to allow only the $\frac{1}{n}$th part of the current to go through the galvanometer, or, in other words, let $C_1 = \frac{C}{n}$. In this case we shall have from (1)

$$\frac{C}{n} = \frac{S}{G+S}C, \quad \text{or } S = \frac{G}{n-1}. \quad . \quad . \quad . \quad (2)$$

from which we find as follows for the values of n in common use:—

If $n=10$	$S = \frac{1}{9}$ of G.
$n=100$	$S = \frac{1}{99}$ of G.
$n=1000$	$S = \frac{1}{999}$ of G.

The positions *a*, *b*, and *c* are marked either with the numbers $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, implying the fractions of the whole current which they pass through the galvanometer, or with the numbers $\frac{1}{9}$, $\frac{1}{99}$, $\frac{1}{999}$, implying the ratio between their resistances and that of the galvanometer.

Lesson XXXIII.—The Box of Coils used as a Bridge.

70. *Exercise.*—To learn the use of a box of coils for measuring resistance by Wheatstone's method.

Apparatus.—(1.) *The Box of Coils.*—One of the best-known arrangements is the *Post Office Resistance Box.* A plan of this box will be seen in Fig. 86, in which AC and AB are

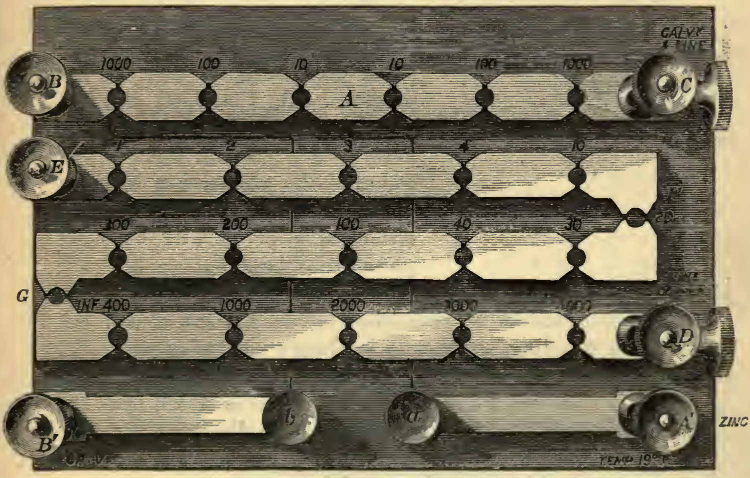


Fig. 86.—The Post Office Resistance Box.

the proportional arms, and EFGD the rheostat arm. The bridge will best be understood by comparing it with the typical diagram (Fig. 87), in which the parts are lettered in the same way as in the figure of the box. At A (Fig. 86) no binding screw is provided, but a wire passes under the ebonite top of the box to a stud at *a*, so that on pressing the key *a*A′ the binding screw at A′ is in connection with A. In like manner the terminal at B′ may be put in contact with the point B by pressing the key

B′*b*. The rheostat arm is connected with the proportional arms by a brass connecting piece (not shown), which ought to be strongly clamped by the binding screws at B and E. At C and D are double binding screws—one for the wire of the unknown resistance, or line wire, besides which there will be the galvanometer wire at C and the battery wire at D. The order in which the various resistances occur will be seen in the diagram. At the place marked INF is the plug called the "*infinity plug.*" Should this plug be removed the connection between the parts of the rheostat arm on either side of it will be completely broken.

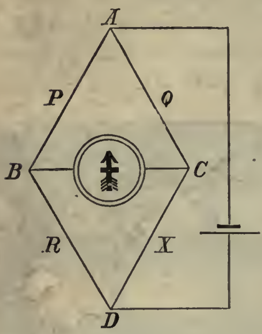


Fig. 87.

(2.) *The Leclanché Battery.*—This form of battery is chosen for measurements of resistance, since it deteriorates but little on standing, so that it is always ready for use. On the other hand, it runs down very rapidly when short-circuited. But when the circuit resistance is small, as is the case when our object is rather to find the direction of deflection than to measure its amount, the current is only required for a few seconds at a time, and in this case any variation in the strength of the current is of little consequence. Again, when the current is required for a longer period, as it is when accurate determinations are being made, the resistance in the circuit will necessarily be so high that the constancy of the battery will be unaffected, inasmuch as it is doing little work. It is convenient to have four cells of this battery fitted with a switch, so that 1, 2, 3, or 4 cells may be thrown into circuit as required (see Appendix).

(3.) *The Connecting Wires.*—These should be of gutta-

percha covered copper wire. The wires leading to the galvanometer and battery may be No. 20 B.W.G. Those leading to the unknown resistance should, however, be thicker, and be provided with copper strips soldered at the ends, as we have shown in Fig. 40. The use of these strips ensures a greater surface of contact.

Method of making the Connections.—In Fig. 88 we have a plan of the connections where G is the galvanometer, S

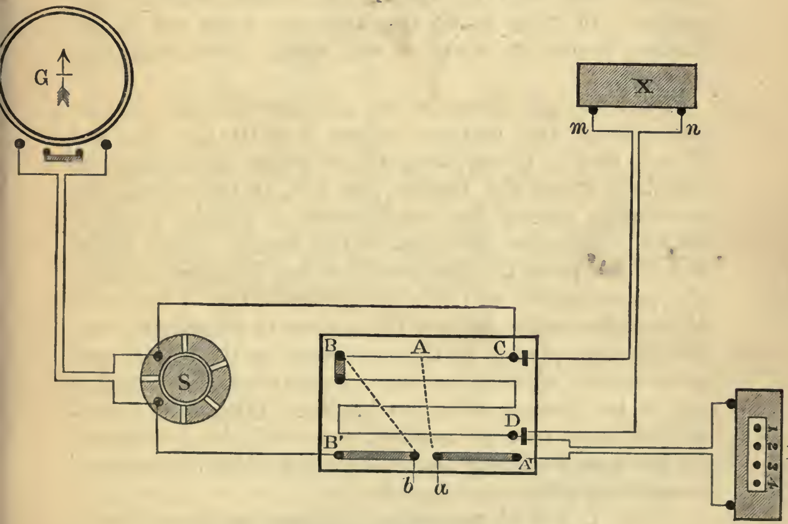


Fig. 88.—Connections for Measuring Resistances.

the shunt, X the unknown resistance, L the Leclanché battery, and CBB′A′ the Post Office bridge. The wires going to the same parts should be brought together as much as possible. When *a* and *b* are pressed down, the contacts indicated in the figure are made. The galvanometer should be at least a mètre away from the

measuring apparatus, and if the resistance to be measured consists of many turns of wire, it is necessary that it should be so far distant that it cannot directly affect the galvanometer.

Method of Measuring Resistances.—The resistance of the connecting wires that go to the unknown resistance should first be measured. (We shall suppose that these wires are each about two yards long: for the purpose of distinction they will be spoken of as the *resistance connectors.*) In order to do this, take the wires out of the binding screws at m and n, and clamp their extremities together.

Place the $\frac{1}{999}$ shunt in the galvanometer, and put on one cell of the battery. Make $P = 10$, $Q = 10$, and $R = 0$, that is to say, keep all the plugs of the rheostat arm in. Press the battery key *first*, in order that the momentary current due to self-induction may have ceased before bringing the galvanometer into circuit. Then, whilst it is down, press the galvanometer key for a few seconds. The galvanometer will now be deflected, say to the *right*. If no deflection is obtained there must be a faulty connection at some place. In this case examine the battery and galvanometer connections, and especially ascertain whether any of the leading wires are broken. With gutta-percha covered wires such an accident may easily be overlooked, for the wire frequently becomes broken while the covering remains complete.

Next, P and Q remaining the same as before, make $R = \infty$. On pressing the keys momentarily as before, the deflection should now be to the *left*, *i.e.* in the opposite direction, for the leading wires should have a resistance between that of $R = 0$ and $R = \infty$. If the deflections are not in opposite directions the connections are probably wrong, and should be examined. Various resistances must now be tried, until a balance is obtained. The order of procedure will best be seen by studying the

following table, which gives the result of an actual measurement. The student is advised to arrange his results in this form until he is quite familiar with the use of the bridge.

No. of Cells.	Shunt.	P.	Q.	R.	Value of X which would balance = $\left(\frac{QR}{P}\right)$	Deflection.
1	$\frac{1}{999}$	10	10	1	1	To right.
1	$\frac{1}{999}$	100	10	1	·1	To right.
1	$\frac{1}{99}$	1000	10	1	·01	To left.
4	No shunt	1000	10	6	·06	To right.
4	No shunt	1000	10	5	·05	To left.

From this we see that the resistance of the leading wires is between ·05 and ·06 ohm. To obtain this resistance more accurately the extent of the deflections must be noted in the last two cases, and the true value of X found by *interpolation*, as shown below:—

Value of $\frac{QR}{P}$.	Deflection.
·06 ohm	36 divisions to right.
·05 ,, ...	37 ,, left.

Hence ·01 causes a difference of seventy-three divisions, and hence the value of $\frac{QR}{P}$, which would correspond to no deflection of the galvanometer, will be $\frac{QR}{P} = X = \cdot 05 + \frac{\cdot 01 \times 37}{73} = \cdot 05507$ ohm approximately.

The resistance of the leading wires being known, the measurement of the resistance of several coils should be proceeded with, as exhibited in the following examples:—

Examples.—I. Galvanometer coil of copper—

$P=100$, $Q=10$, $R=9896$, $\frac{QR}{P}=989\cdot 6$. No deflection.

,, ,, ,, 9897, ,, 989·7. Slight deflection.

$X=989\cdot 6 - \cdot 055 = 989\cdot 545$ ohms. Temp. 15° C.

II. Galvanometer coil of copper—

$P=1000$, $Q=10$, $R=1020$, $\frac{QR}{P}=10{\cdot}20$. Deflection of -4.

" " 1019, $10{\cdot}19$. " $+21$.

$$X=10{\cdot}19+\frac{{\cdot}01\times 21}{25}-{\cdot}055=10{\cdot}143.$$

CHAPTER VI.

THE QUADRANT ELECTROMETER.

71. THE quadrant electrometer bears the same relation to electrostatic measurements that the mirror galvanometer bears to electro-magnetic measurements. The indications of the scale of the latter may be considered as directly proportional to the currents passing through its coil, and those of the former to the differences of potential at the terminals of the electrometer. The chief use of an electrometer in the laboratory is in comparing the electromotive forces of cells in open circuit. It is also of great value in studying the production of a difference of potential by other than chemical means. In the cable factory and at cable stations it is employed for testing the insulation of submarine cables after the manner of the method of Lesson VIIc. In many tests it may replace the galvanometer with much advantage, such, for instance, as that of Lesson XXV.

LESSON XXXIV.—Use of Quadrant Electrometer.

72. *Exercise.*—To compare the electromotive forces of a Daniell's cell, taken as a standard, with two other Daniell's cells, (1) separately, and then (2) placed in series, and (3) in multiple arc.

Apparatus.—(1.) The quadrant electrometer of Figs.

89 and 90 is of a simple and workable form. It consists of a wooden box, mounted on three levelling screws, with a wooden door at the back and a glass one in front. The woodwork is almost entirely, and the glass front is partly, coated with strips of tinfoil. To prevent confusion, neither the front nor the back is shown in the figure. There are three holes in the top of the box. The central one is for the reception of a long glass tube, fitted in its place by means of a cork. At the top of the tube is the *charging electrode* C, which is provided with a small binding screw, supported on the top of a rod of ebonite, fitted by a cork into the top of the tube. The binding screw is in connection with an extremely fine silver wire that supports the mirror M and the aluminium paddle-shape needle seen in Fig. 90. Through the other holes in the top of the case pass the *charging electrodes* A and B. These consist of ebonite rods, terminating in binding screws in connection with wires leading to the quadrants. The quadrants consist of four brass boxes, open along the inner edges. They are seen in elevation in Fig. 89 and in plan in Fig. 90, at A_1, B_1, A_2 and B_2. They rest on a

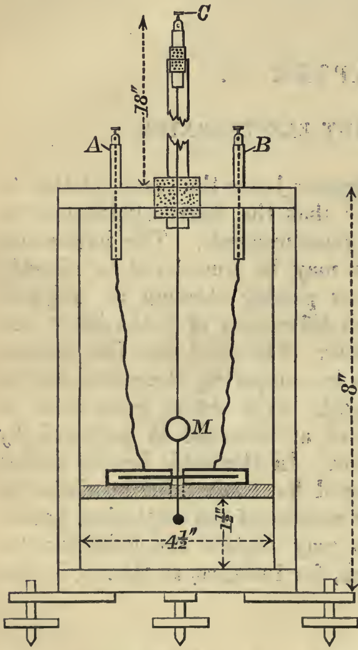


Fig. 89.

sheet of ebonite, to which three of them are permanently screwed. It is better that the fourth should be adjustable. The alternate quadrants are connected together, as shown in Fig. 90; thus A_1 is connected with A_2 and B_1 with B_2. Within the quadrants is suspended the needle. From the lower surface of the needle hangs a small weight, which may also act as a damper, and which is useful in levelling the instrument. A piece of looking glass below this weight may be used to assist in the operation. (2.) A water battery consisting of small cells containing zinc and copper strips, and charged with water,

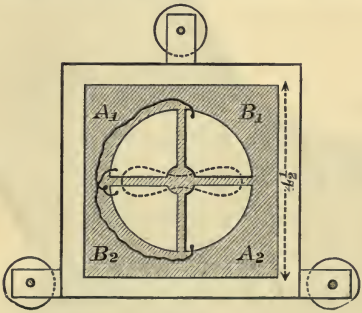


Fig. 90.

will be required. Fig. 91 shows a convenient form of the battery. (3.) Lamp and scale.

Principle of the Instrument.—One pole of the water battery is connected with C, and the other pole is put to earth. The needle is thereby raised to a certain potential V, which may be regarded as constant. If the needle lies symmetrically with regard to the quadrants in the position shown in the figure it will remain undeflected, providing that all the quadrants are at one potential. Should, however, A_1 and consequently A_2 be at a potential V_1, and B_1 with B_2 at a potential V_2, then the needle will turn through a certain angle, depending upon the torsional rigidity of

the wire which opposes the motion. If V is high compared with V_1 and V_2, then the amount of deflection will be proportional to $V_1 - V_2$.[1]

Method of Use.—(1.) Set the instrument about one mètre from the lamp and scale. (2.) Level until the needle is central. (3.) Put the electrodes A, B and C to earth. (4.) Make the spot of light central by turning C.

Fig. 91.—A Water Battery.

(5.) Connect C with one pole of the water battery, the other pole being earthed. (6.) If the light does not remain central, shift the movable quadrant. (This adjustment in some instruments is done once for all by the maker.) (7.) Leave A earthed, but insulate B and connect it with one pole of the cell to be tested, the other pole of which is

[1] For proof see *Elementary Practical Physics*, vol. ii. p. 431.

earthed. (8.) Read the deflection. (9.) Disconnect the pole connected to B and earth B a short time in order to discharge the quadrants. (10.) The poles of the cell that were connected respectively to B and to earth must now be reversed. (11.) Again read the deflection. The number of divisions that the spot of light has passed over in the two positions is proportional to the E. M. F. of the cell. (12.) Repeat the operations several times and take the mean of the deflections.

Note.—These operations may be performed more readily with a specially designed electrometer key.

(13.) Replace the cell by a second one and proceed as before.

Example.—Cell α.

Experiment.	− pole to earth, + pole to B.	+ pole to earth, − pole to B.	Total Deflection Division.
1	+51	−53	104
2	+50	−55	105
3	+52	−50	102
		Mean .	103·7 nearly.

Cell β gave 108·1 divisions. Cell γ gave 102·8 divisions. Cell β and γ in series gave 212·0 divisions, and in multiple arc 106·2 divisions.

Taking α as 1·1 volt, β is

$$\frac{1\cdot 1 \times 108\cdot 1}{103\cdot 7} = 1\cdot 15 \text{ volt.}$$

Similarly the other values can be expressed in volts.

APPENDIX

A.

ADDITIONAL PRACTICAL DETAILS.

1. *Switch for Battery.*—Fig. 1 shows the general arrangement of a switch for one or two cells. A metal bar SS_1, provided with a handle at S_1 and pivoted at S, may be placed in contact with any one of three metal segments, 0, 1, and 2, that are fixed

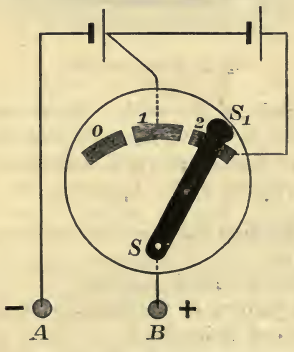


Fig. 1.—Battery Switch.

to a wooden or ebonite block. When the switch is at 0 both cells are out of the circuit that connects A and B, and according as the switch is at 1 or 2 one or two cells are in circuit. Instead of a pivoted switch a plug switch is often used.

2. *Silk for Suspension of Galvanometer Needles.*—The best silk is obtained from the middle of a good cocoon. The cocoon should be steeped in tepid water, and the silk wound off it on to a simple reeling machine. Fig. 2 shows such a machine, in which the reel R is made of a number of glass rods that connect

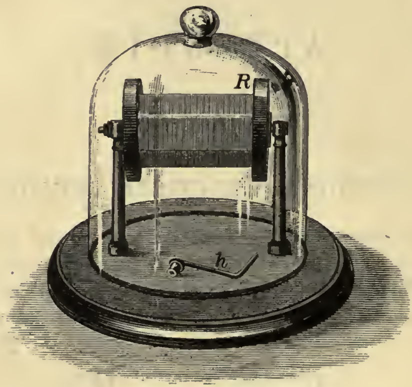


Fig. 2.—Reel for Silk.

the two wooden ends of the reel. When the silk has been wound, the handle *h* should be removed, and the whole covered by a glass shade to protect the silk from dust. See also *Elementary Practical Physics*, vol. i. Appendix C.

3. *Clamp and Binding Screws.*—The various patterns of these are shown in Fig. 3.

1 is of the ordinary French pattern.

1*a* is a special pattern of the same, with a second binding screw at the end of its shank.

2 is an ordinary telegraphic binding screw.

2*a* is the same with a lock nut.

2*b* is the same with a double-screw for use with two separate wires.

3 and 3*a* are common clamp screws for connecting two wires.

3*b* is the telegraphic pattern that is also useful for connecting plates.

4 is a battery clamp.

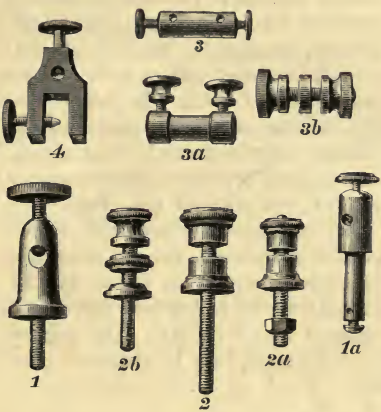


Fig. 3.—Clamp and Binding Screws.

4. *Soldering.*—Perhaps no operation in the electrical laboratory is so important or requires to be performed so often as soldering; hence a few details relating to it will be useful. The materials requisite are a small soldering iron, soft solder, and a means of heating the iron. We find the soldering-iron heater of Fletcher very useful for the purpose. There will further be necessary either powdered resin or chloride of zinc for enabling the solder to make good contact. The former material is much to be preferred for electrical apparatus, but it is more difficult to solder by its means than by the chloride of zinc. When the latter is used the soldered place should afterwards be washed, otherwise galvanic corrosion will take place at the joint.

5. *Substitutes for the Mirror Galvanometer.*—As it is not always convenient to use this instrument, it may be useful to describe some substitutes. (1.) *Simple Current Detector.* Take a piece of glass tubing 5 inches long and 1 inch in diameter. Wind

a coil round one end, giving each layer a coating of hot paraffin wax, which will bind the strands together. The tube must be used with its long axis horizontal. Suspend by a silk fibre from a cork (which closes one end of the tube) a magnetic needle so as to be in the centre of the coil. The needle must be provided with a long pointer, reaching to the distant end of the tube, which likewise must be closed with a cork. Mount on a base-board with binding screws. (2.) *The Astatic Current Detector.* A more delicate instrument may be made on the principle of the ordinary astatic galvanometer,[1] constructed in a simple manner by using a postal box fitted like the comparison magnetometer of page 101, but without the arms. (3.) *Proportional Galvanometer.* An instrument, whose scale divisions are nearly proportional to current strength, may be made after the manner of either of the above instruments, but it will be necessary to have the pointer at least 12 inches long and capable of moving over a linear scale of 200 divisions. The pointer, which must be very light and yet rigid, may be either of glass fibre, aluminium, or straw.

B.

PRICE LIST OF APPARATUS AND MATERIALS.[2]

The apparatus and materials may be obtained from Mr. W. Groves, 89 Bolsover Street, Portland Place, London. The apparatus marked * is of a specially designed pattern, approved by the authors, and of which Mr. Groves *is the only authorised maker.* Mr. Groves supplies the apparatus of two classes. That of class B is made of varnished pine, and has paper scales. That of class A is of hard wood polished, has boxwood scales, and is of altogether superior workmanship.

[1] See *Elementary Lessons in Physics*, by Balfour Stewart.

[2] Many of the prices must be regarded as only a guide; definite prices cannot be given, owing to the great variation in the dealers' lists and current market prices.

I. *General.*

		£	s.	d.
Bunsen burners	from	£0	1	6
Drawing-board		0	2	6
T square and set square		0	2	0
Callipers, inside and outside		0	2	6
Slide callipers, reading to ·1 mm.; length, 15 cm.		0	10	0
Imperial standard sheet-metal gauge		0	8	0
Micrometer wire-gauge		1	10	0
Balance (Becker's)	from £1 : 5s. to	3	3	0
Box of weights, 100 to ·01 grm.	10s. to	0	15	0
Fletcher's blowpipe		0	7	6
Foot-bellows for same		1	5	6
*Model of Vernier in wood		0	5	0
*Circular protractor, with radial arm (Fig. q), Class A, brass scale, 15s.; Class B, paper scale		0	5	0
Glass rod and tubing	per lb.	0	1	0
Test tubes	per dozen, 3d. to	0	1	0
*Box containing silk fibre, cocoon silk, silk thread, and ribbon		0	1	6
Copper wire, cotton covered, per lb., No. 18, 1s. 6d.; No. 28, 3s.; No. 36		0	5	0
,, Gutta-percha covered, per dozen yards, No. 16, 3s.; No. 20		0	1	6
Retort stands	from 1s. 6d. to	0	3	6
Tripod stands	from 9d. to	0	2	0
India-rubber tubing for gas connections	per foot	0	0	4
Wooden blocks for supports (various)		0	2	0
Iron clamps for fixing apparatus to bench	each	0	1	6
Glass cutter		0	1	6
Evaporating basins	from 6d. to	0	2	0
Beakers	in nests, from 2s. to	0	5	0
Cork borers	set of best	0	6	0
Corks	per dozen, from 2d. to	0	0	9
Telegraph binding screws	per dozen, from 2s. to	0	6	0
Clamp screws for connecting wires	per dozen	0	3	0
German-silver wire, covered with silk, per lb., from 10s. 6d. to		1	1	0

II. *Electrostatics.*

Two pieces of glass tubing (Fig. 1)	0	1	6
Supporting hook for same (Fig. 1)	0	0	6
Two polished ebonite rods	0	1	0
Pad of silk containing three thicknesses of flannel	0	1	6
Catskin or other fur	0	1	6
*Two gold-leaf electroscopes (Fig. 2)	0	5	0
*Tin can with insulated bottom	0	1	0

	£	s.	d.
Block of paraffin wax	£0	1	0
Stand for supporting glass rod, etc., when testing insulation (Fig. 3a—Note)	0	2	6
*Two Brass knobs, mounted (Fig. 4)	0	3	6
*Electrophorus (Fig. 5)	0	2	6
*Tin can with insulating handle (Fig. 6)	0	1	0
*Apparatus showing + and − electricity produced in equal amounts (Fig. 8)	0	3	6
*Perforated zinc cover for Fig. 9	0	1	0
*Drying oven of tin, with Fletcher's burner (Fig. 2a)	0	7	0
Gold-leaf electrometer (Figs. 10 and 10a) Class A, 15s.; Class B	0	7	6
*Tin can, with inner insulated can forming an air condenser	0	2	0
* ,, with paraffin between the tins	0	2	6
*Ebonite cup for oils (page 55)	0	2	6
*Insulated condenser like Fig. 11, but improved, so that lid is separately supported and adjustable, Class A, £1; Class B	0	10	0
Electrical amalgam in box, 2 oz., mixed with tallow	0	1	0
*Collection of insulators of different kinds, in box, for experiments of page 33	0	2	6
Goldbeater's pad, knife, and tip	0	2	9
Gold leaf . . . per book	0	1	3
Dutch leaf . . . per book	0	0	3
*Simple quadrant electrometer (Fig. 89) Class A, £2; Class B	1	10	0
*Water battery of 100 cells (Fig. 91) Class A, £2; Class B	1	10	0

III. *Magnetism.*

	£	s.	d.
Pair bar magnets and keepers in box	0	3	0
Horse-shoe magnet in box	0	3	6
*Knitting-needles, sewing-needles, watch-spring, soft iron nails, pieces of soft iron, crinoline steel, ferrotype iron, sheet of steel, strip of tinned iron, two brass clamps	0	4	0
Iron filings in bottle, with muslin	0	0	6
Steel filings in bottle	0	0	6
Long thin bar magnet	0	2	0
Small pocket compass	0	1	0
*Azimuth compass (Fig. 18) . Class A, 9s.; Class B	0	6	0
*Dip circle (Fig. 26) . Class A, £1 : 15s.; Class B	0	16	6
*Deflection magnetometer (Fig. 33) Class A, £1 : 12s.; Class B	0	17	0
*Magnets for same . . . each	0	1	0
*Comparison magnetometer (Fig. 36) Class A, £2; Class B	0	16	6
*Four magnets for same	0	2	6
*Spring balance (Fig. 37) . Class A, £1 : 5s.; Class B	0	15	0

*Vibration box with stirrups (Fig. 35) Class A, 15s.; Class B	£0	8	6
*Two magnets, and two brass bars for same . . .	0	2	6
Paraffin wax . . . . per lb.	0	1	0
Paraffin bath of sheet-iron, with iron stand . . .	0	5	0
Sealing-wax varnish . . . . per bottle	0	1	0
Coaguline cement . . . . per bottle	0	1	0
*Magnetoscope (Fig. 13) . . . Class A, 4s.; Class B	0	2	0

IV. *Voltaic Electricity.*

*Two pint Bunsen cells in box (Fig. 38)	0	8	0
*Two pint Bichromates in box, with lifting arrangement (Fig. 39)	0	10	0
*Pohl's commutator (Fig. 42)	0	6	6
*Magnet suspended for telescopic stand (Fig. 43) . .	0	4	0
*Wire one mètre long (Fig. 43)	0	3	6
*Daniell's cell (Fig. 46)	0	3	6
*Plating bath (Fig. 47)	0	6	0
Scratch brush (Fig. 48)	0	1	0
*Galvanoscope and sliding stage (Fig. 52) Class A., £1 : 10s. Class B	0	10	0
*Mirror galvanometer (Fig. 59) Class A, £1 : 10s.; Class B	0	16	6
*Scale and lamp for same (Fig. 62, but improved) . .	0	10	0
Set of shunts for same	0	10	0
*Box of coils, with proportional arms (Fig. 86)[1] . . .	6	0	0
Plug key (Fig. 67)	0	2	6
*Coil of high resistance, 5000 ohms in coil	0	6	0
*Wheatstone's bridge . Class A, £1 : 10s.; Class B	0	15	0
*Current detector (see Appendix A) Class A, 14s.; Class B	0	10	0
*One-ohm coil . . . . . Class A, 10s.; Class B	0	5	0
*Tangent galvanometer, hoop and stand (Fig. 79) Class A, £1 : 5s.; Class B	0	15	0
*Straight Rheostat (Fig. 66) . Class A, 14s.; Class B	0	10	0
Measuring vessels	0	1	6
Four-inch glass funnel	0	0	6
Stoneware jug	0	1	6
File for battery and wires	0	0	9
Stiff nail brush	0	0	6
Sulphuric acid (commercial) . . . . . per lb.	0	0	2
Nitric acid (commercial) . . . . . . per lb.	0	0	6
Copper sulphate (commercial) . . . . . per lb.	0	0	5
Zinc sulphate (commercial) . . . . . per lb.	0	0	3
Mercury . . . . per lb.	0	2	6
Platinum foil . . . . per square inch	0	0	6
Platinum wire . . . . per inch	0	0	1

[1] These are sufficiently accurate for all school work.

Caustic soda	per lb.	£0	0	6
Emery paper	per sheet	0	0	3

V. *Parts of Apparatus.*

Boxwood scales divided into millimètres	2s. to	0	10	0
Paper scales divided into millimètres		0	1	0
Paper circles divided into degrees	1s. and	0	0	6
Postal boxes	1d. to	0	1	0
Mirror glass		0	1	0
Cardboard		0	0	6

C.

THE PHYSICAL LABORATORY WORKSHOP.

No physical department of a school can be considered complete without being provided with a workshop. This room need not be large; it should, if possible, be on the basement and near the laboratory.

The following list will serve as a guide for the kind of fittings, tools, and materials requisite.

I. *Fittings.*

Joiner's bench, 10′ long, 2′ 6″ broad, 32″ high, with deal top and frame fitted with a bench-vice and dog and tool rack at the back.

Mechanic's bench, 10′ long, 2′ 6″ broad, 34″ high; pine top 3″ thick, fitted with vice and tool rack at the back.

Soldering bench, 3′ long and 2′ broad, with blowpipe and jet for Bunsen burner. On the pine top should be a sheet of $\frac{1}{8}$″ iron.

Grindstone to work by foot power—stone 2′ diameter, with trough for water £1 5 0

II. *Lathe and Lathe Tools.*

A well-finished lathe, with machine-planed iron gap-bed, back-geared headstock, steel mandril and tee rests, face plate, fitted together on iron stand 7 0 0

Three-jawed steel chuck	£1	0	0
Set of turning tools for wood	0	3	6
,, ,, for metal	0	3	6
Half set of twist and plain drills on stand $\frac{1}{16}''$ to $\frac{1}{2}''$	1	0	0
Milling wheel with handle	0	2	0

III. *Joiner's Tools.*

Set of bench planes—trying, 6s. 6d.; jack, 4s. 9d.; smoothing, 3s. 9d	0	15	0
Cross-cut saw	0	5	0
Tenon saw	0	5	6
Lock saw, 12″	0	1	4
Plough and bits	1	0	0
Two hammers	0	3	4
Mallet	0	2	0
Spoke-shave	0	0	10
Brace and bits	0	15	0
Two screwdrivers, 9d. and 1s. 2d.	0	1	11
Four chisels, $\frac{1}{4}''$, $\frac{5}{8}''$, 1″, and $1\frac{1}{2}''$	0	3	6
Gouge, $\frac{1}{2}''$	0	0	9
Bevel, 2s. 3d.; 6″ square, 1s. 10d.	0	4	1
2′ rule	0	1	6
Six sprigbits, 10d.; four gimlets, 1s. 6d.	0	2	4
Compasses, 8″, 2s.; pincers, 8″, 2s.	0	4	0
Two marking gauges	0	1	6
One oilstone, 1s. 6d.; slip, 5d.; oil-can, 5d.	0	2	4
One scraper, 5d.; cork rubber, 4d.; two punches, 4d.	0	1	1

IV. *Mechanic's Tools.*

One pair outside callipers, 6″	0	1	6
One pair inside ,, 6″	0	1	6
One steel square, 5″	0	2	6
One pair spring dividers, 7″	0	3	0
12″ steel rule	0	1	6
Centre punch	0	0	6
Hand-vice	0	2	3
One pair each of round-nose, flat-nose, and cutting pliers	0	5	6
One 10″ half-round file, and one 10″ hand file	0	2	0
One 8″ square file, and one 8″ round file	0	1	4
Cutting shears	0	2	6
Cold chisels, $\frac{1}{4}''$, $\frac{1}{2}''$, and $\frac{3}{4}''$	0	3	0
Notched screw-plate and taps	0	10	6
Bench vice	0	15	0
Tinsmith's anvil	0	10	0
Wrench	0	6	0

Soldering iron		£0	1	4
Metal saw		0	4	6

V. *Materials.*

Boards of pine, 1″, ¾″, and ½″ thick, 3½d., 2½d., 2d. per foot respectively.

Boards of baywood, 1″, ¾″, and ½″ thick, 7d., 6d., 5½d. per foot respectively.

Sheet tin	per sheet	0	0	5
Sheet copper	per lb.	0	0	7½
Sheet zinc	,,	0	0	3½
Sheet brass	,,	0	0	6
Solder	,,	0	0	11
Glass paper	per dozen sheets	0	0	9
Emery paper	,, ,,	0	0	9

D.

THE RECORDING AND CALCULATING RESULTS OF EXPERIMENTS.

A great part of the value of Physical Laboratory work will be lost if the student is not taught to systematically record the results of his experiments in a suitable note-book. The use of loose sheets of paper is very objectionable. The notes may be taken in pencil in the laboratory, and copied out into a larger note-book in ink at home. Calculations and sketches should be shown on the left-hand page, and observations, descriptions, formulæ, and theory on the right-hand side. We would advise the use of note-books ruled into squares, as they are convenient for plotting curves, and a help in drawing to scale. The calculations should be made by the aid of four-figure logarithms, which give sufficient accuracy. We cannot sufficiently urge the importance of young students being taught to use such tables, and we see no reason why the use of logarithms should not be included in the arithmetical courses of schools. Unfortunately, as the school mathematical work is at present arranged, students

are not introduced to logarithms until they are fairly well advanced with trigonometry. Every student should have a copy of one of the cheap editions of mathematical tables that are now published, which for the purpose of this work must at least contain—

(1) A table of four-place logarithms.
(2) A table of four-place anti-logarithms.
(3) A table of natural tangents to tenths of a degree.
(4) A table of logarithmic tangents to tenths of a degree.

With the aid of such tables, the teacher is advised to work through with the student the following example of the method of recording and calculating results :—

Example.—

Calculation of $\frac{M}{H}$—

$$\frac{M}{H}=\frac{(25{\cdot}15+5{\cdot}15)^2(25{\cdot}15-5{\cdot}15)^2}{2(25{\cdot}15)}\tan 28^\circ\,30',$$

$$=\frac{(30{\cdot}3)^2(20)^2}{50{\cdot}3}\tan 28^\circ\,30'.$$

$$\begin{array}{rr}
\log 30{\cdot}3 = 1{\cdot}4814 & \log 20 = 1{\cdot}3010 \\
2 & 2 \\
\hline
2{\cdot}9628 & 2{\cdot}6020 \\
2\log 20 = 2{\cdot}6020 & \\
\text{Log}\tan 28^\circ\,30' = 9{\cdot}7348 & \\
\hline
5{\cdot}2996 & \\
\log 50{\cdot}3 = 1{\cdot}7016 & \\
\hline
\log\frac{M}{H} = 3{\cdot}5980 &
\end{array}$$

Determination of M and H by the method of Lesson XVI.

Deflection Observations—

$$\frac{M}{H}=\frac{(d+l)^2(d-l)^2}{2d}\tan\alpha.$$

$d=25{\cdot}15$ cm. $l=5{\cdot}15$ cm.

	End of Needle		
Position.	East.	West.	Mean.
1	28·5	28·7	28·6
1*a*	28·2	28·6	28·4
2	28·3	28·1	28·2
2*a*	28·6	29·0	28·8
		Mean of means	28·5 = 28° 30′

$$\frac{M}{H}=3963$$

Vibration Observations—

	h.	m.	s.
Time of starting	11	0	0
Time of 100th oscillation	11	10	50
Time of 100 oscillations		10	50
		60	
	100) 650		
	$t=$ 6·5 sec.		

Calculation of I—

$$I = 68{\cdot}6\frac{(10{\cdot}3)^2+(1{\cdot}4)^2}{12} = 617{\cdot}7$$

$$\begin{array}{r} 10{\cdot}3 \\ 10{\cdot}3 \\ \hline 309 \\ 1030 \\ \hline 106{\cdot}09 \\ 1{\cdot}96 \\ \hline 12\,)\,108{\cdot}05 \\ \hline 9{\cdot}004 \\ \hline \end{array} \qquad \begin{array}{r} 1{\cdot}4 \\ 1{\cdot}4 \\ \hline 5{\cdot}6 \\ 14 \\ \hline 1{\cdot}96 \\ \hline \end{array} \qquad \begin{array}{r} 68{\cdot}6 \\ 9{\cdot}004 \\ \hline 2744 \\ 617400 \\ \hline 617{\cdot}7 \\ \hline \end{array}$$

Calculation of MH—

$$MH = \frac{(3{\cdot}142)^2\,(617{\cdot}7)}{(6{\cdot}5)^2}.$$

$$\begin{array}{rl} \log 3{\cdot}142 = & {\cdot}4972 \\ & 2 \\ \hline 2\log 3{\cdot}142 = & {\cdot}9944 \\ \log 617{\cdot}7 = & 2{\cdot}7908 \\ \hline & 3{\cdot}7852 \\ 2\log 6{\cdot}5 = & 1{\cdot}6258 \\ \hline \log MH = & 2{\cdot}1594 \\ \hline \end{array} \qquad \begin{array}{rl} \log 6{\cdot}5 = & {\cdot}8129 \\ & 2 \\ \hline & 1{\cdot}6258 \end{array}$$

Calculation of M *and* H—

$$\begin{array}{rl} \log MH = & 2{\cdot}1594 \\ \log \frac{M}{H} = & 3{\cdot}5980 \\ \hline 2\,) & 5{\cdot}7574 \\ \hline \log M = & 2{\cdot}8787 \\ \hline 2\,) & \bar{2}{\cdot}5614 \\ \hline \log H = & \bar{1}{\cdot}2807 \\ \hline \end{array}$$

Determination of Moment of Inertia—

W = 68·6 grms. a = 10·3 cm. b = 1·4 cm.

$$I = W\frac{a^2+b^2}{12}.$$

$$I = 617{\cdot}7.$$

Determination of MH—

$$MH = \frac{\pi^2 I}{t^2}.$$

$$MH = 144{\cdot}3$$

Determination of M *and* H—

$$M = \left(MH\cdot\frac{M}{H}\right)^{\frac{1}{2}} = 756{\cdot}3.$$

$$H = \left(\frac{MH}{\frac{M}{H}}\right)^{\frac{1}{2}} = {\cdot}1906.$$

E

THE REQUIREMENTS OF A PHYSICAL LABORATORY FOR SCHOOLS.

1. *The Laboratory Fittings.*—We can give the best idea of the requirements of a physical laboratory by describing the chief arrangements of three recently-fitted laboratories.

(1.) *The Manchester Grammar School* (see Plan, Fig. 4).—The old English room on the basement has recently been converted into a physical laboratory. It has the following fittings:—

AA and AA. These are two long tables specially designed for juniors. Each table has accommodation for twenty boys, who are supposed to work in pairs. The general arrangement of these tables will presently be described.

B and B. Two strong working tables. In the centre of each is a four-way gas tap for Bunsen burners, and a luminous burner mounted on an arm with universal movements.

C. A strong working table, with gas arrangements like B.

D and F are square-topped slate slabs supported on stone piers.

E is a stone pier with a slab of stone on the top. Height only 15 inches.

G and H are slate slabs supported on piers of white brick.

K and L are wooden benches supported from the wall and by front legs.

M with N constitutes a working bench, fixed firmly between the pillar P_1 and the buttress. By drawing down two blinds between M and N the space having F as a centre becomes a dark room, for the remainder of the space is enclosed by a roofed partition 10 feet high. The roof of the dark room is used for storage.

P_2 and P_4 are pillars to which black-boards are fixed.

P_3. Around this pillar a table is fixed.

Q is an extensive series of cupboards and drawers for the storage of apparatus.

R consists of ten cupboards placed 18 inches above the heating apparatus.

S_1, S_2, S_3, and S_4 are sinks.

H_1, H_2, H_3, and H_4 are shelves.

T_1 is a mechanic's bench with lathe, T_2 a joiner's bench, T_3 a chemical bench, T_4 a blowpipe bench. These, together with the fume cupboard U, are separated from the main laboratory by a partition 5 feet high. Above T_3 and T_4 are fume hoods f_1 and f_2.

At V is the demonstrator's table mounted on a platform.

At X is a fireplace. Above W is a strong hook, fastened into the

MANCHESTER GRAMMAR SCHOOL, PHYSICAL LABORATORY

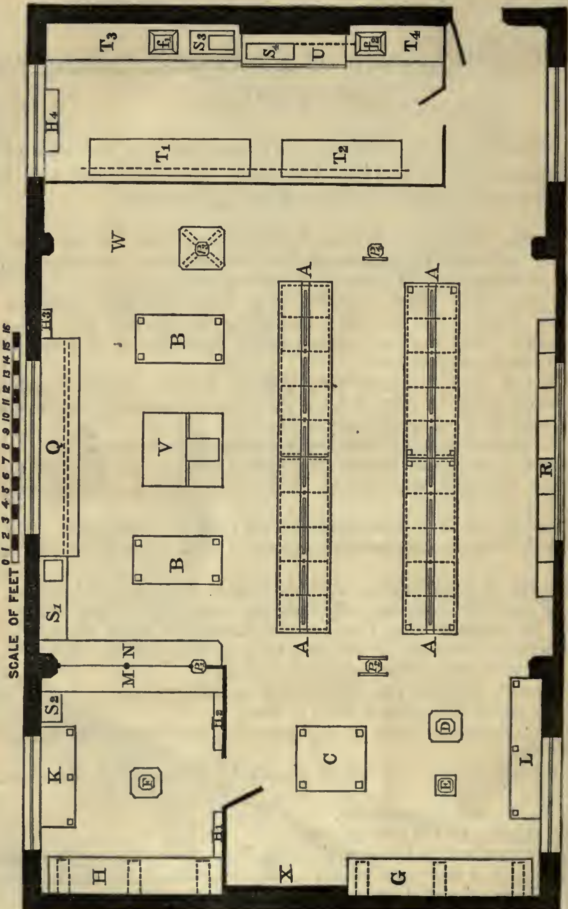


Fig 4.

ceiling, for supporting a Foucault's pendulum. There are also hooks

above D and in the pillars P_1 and P_3 for the support of wires and pendulums.

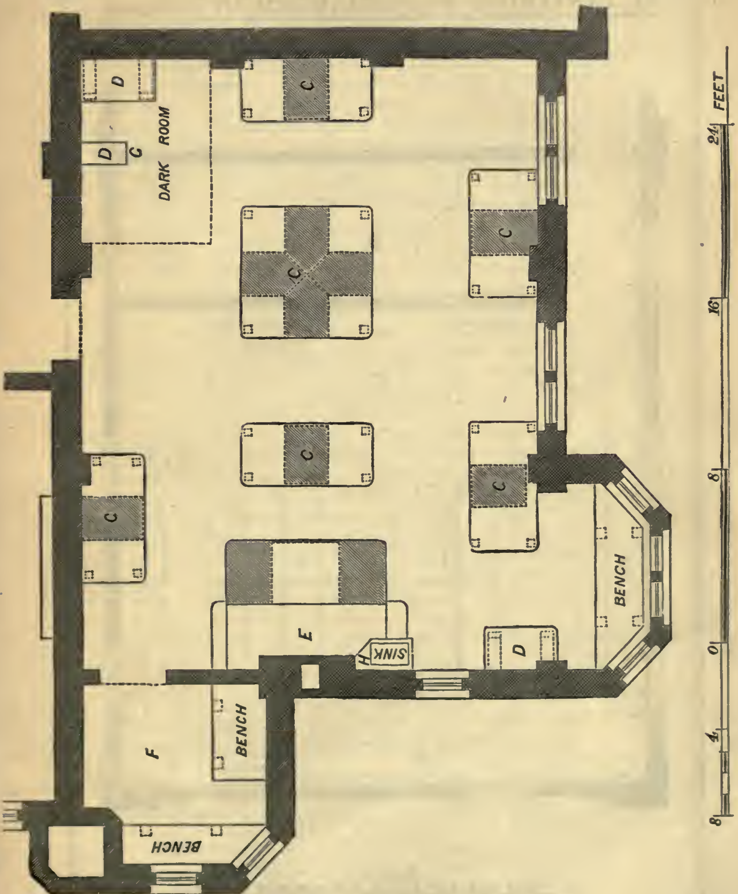


Fig. 5.—Plan of Hulme Grammar School Physical Laboratory.

The regulation height of the benches and slabs is 2 feet 10 inches.

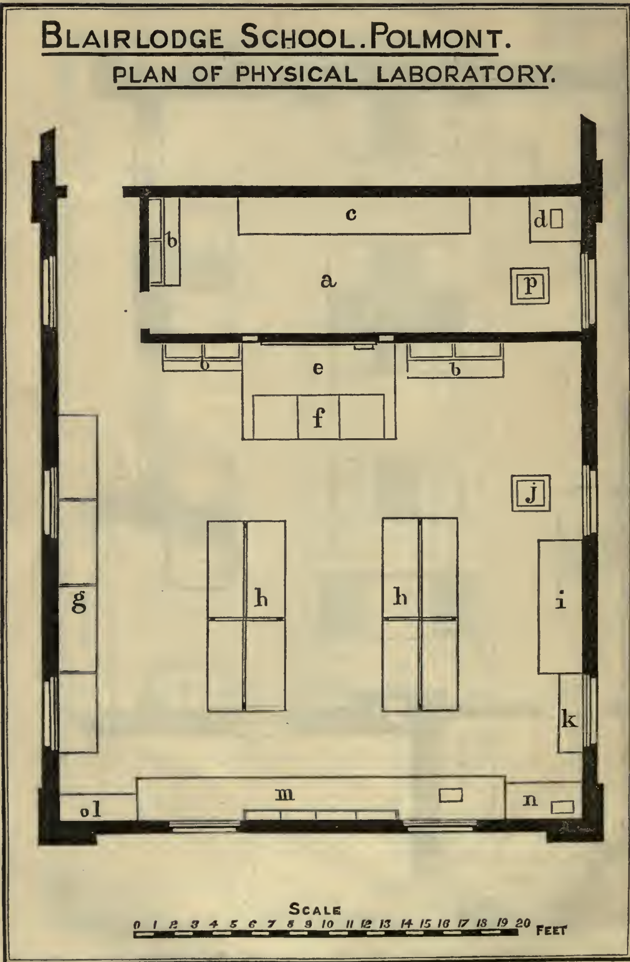

BLAIRLODGE SCHOOL. POLMONT.
PLAN OF PHYSICAL LABORATORY.
c
d
b
a
p
e
b
b
f
j
g
h
h
i
k
m
o l
n
SCALE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 FEET

Fig. 6.

(2.) *The Hulme Grammar School, Manchester* (see Plan, Fig. 5).—The physical laboratory is on the first floor. It is intended to accommodate thirty boys. C are the working tables with cupboards beneath at the shaded portions. D, Slate slabs supported on corbels let into the walls. E, Platform with demonstration table. F, Workshop. G, Dark room with sliding curtains. H, Sink, above which is a Fletcher's hot-water apparatus. The height of the room is 14 feet. It is crossed by two iron girders, which are bared for suspensions. To the left of the outer door and at the left of the window on the extreme right are oak beams 9 feet high that project 2 feet from the wall that are also used for suspensions. At heights of 6 feet and 4 feet respectively wooden belts run round the walls, to which fittings may be secured. Above each table, against the wall, are two iron brackets folding back against the wall. Operations requiring the use of a fume cupboard are carried on in the chemical laboratory. In the basement accommodation has been provided for a larger workshop with lathes.

(3.) *Blairlodge School, Polmont, N.B.* (see Plan, Fig. 6).—This is divided into an elementary and advanced laboratory. The latter (a) forms also a dark room, the top of which is used for storage. It is fitted with a slate slab c, a sink d, a square slate slab p, and an apparatus cupboard b. The demonstrator's seat is at e in the elementary laboratory, and his desk at f. Behind him are two windows, provided with curtains, through which he can overlook the advanced laboratory. The other fittings of the elementary laboratory are three benches for twenty-four juniors, g, h, and h, arranged like those to be presently described. A square-topped slate slab j, a longer slab i for balances, a hinged window shelf k, a long chemical bench m provided with a sink and having cupboards and drawers beneath and shelves above. At n is a stink cupboard, and at l a blowpipe table. Apparatus cupboards are shown at b and b. The laboratory is lit both by gas and electricity. There are dynamo leads to the dark room and the stink cupboard. Below the latter secondary batteries are placed. Arrangements are made for electrically connecting the stink cupboard with the benches and the benches with each other. The school is provided with a well-fitted workshop.

2. *Working Benches for Juniors.*—We shall now give further details of a working bench for juniors, similar to the design adopted at two of the before-mentioned schools.

Fig. 7 shows the front and end elevations of the bench, and also the plan of its top with the overhead rail removed. It is intended to accommodate eight juniors working in four pairs at the positions a, a_1, b, b_1, c, c_1, and d, d_1. It is 10 feet long by 4 feet wide. The height is 2 feet 10 inches. Down the middle of the top of the table is a 4-inch plinth, underneath which is a gas-pipe supplying two standards g and g, each with two two-way gas nozzles for Bunsen's burners (fixed just above the level of the table), and two luminous burners

above the overhead rail. The last mentioned is 4 inches square, and is supported by a central and two end posts *r*, *r*, *r*. The central plinth has two boxwood scales divided into millimètres, let into it flush with the top of the table. These scales are numbered along two edges in such a way that the scales can be used by boys working on both sides of the table. Fixed to the overhead rail are four hinged brackets *b*, *b*, which may be clamped at any position by thumb screws. They serve to support pendulums, etc. A number of hooks are also provided for similar purposes. These are also screwed into the rail, which also is provided with name-plates bearing the names of the boys. It is intended that the gas standards shall take

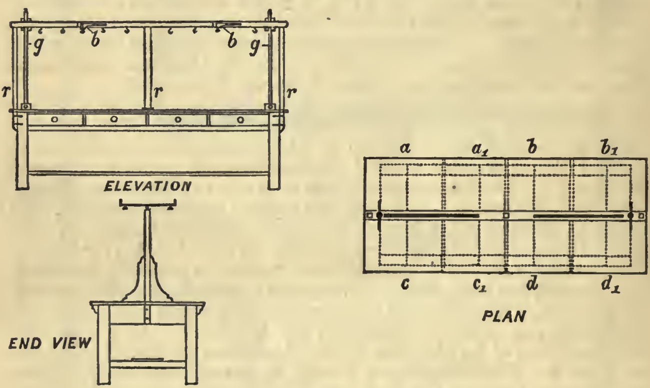


Fig. 7.

the place of retort stands, and that clamps for fixing apparatus shall be screwed to the wooden uprights. The top of the table should project beyond the frame 2½ inches all round, so that apparatus can be clamped down. There are eight drawers each 6 inches deep, divided into partitions along the dotted lines shown. No cupboards are shown, but these may be added if storage room should be required. They should, however, be only at the ends of the benches, as it is important not to interfere with comfortable sitting. The spaces under the tables are useful also for placing stools and supports. In the figure a shelf is shown useful for the reception of batteries, etc. For the purpose of connecting batteries binding screws are fixed in the central plinth, and are in connection with wires beneath the table. Binding screws are also connected with the gas-pipes to serve as "*earths*."

F.

NOTES ON THE ORGANISATION OF LABORATORY WORK.

1. *Mechanical Assistant.*—Every large school requires a mechanical assistant to make and repair apparatus for the laboratory and lecture-room. He should also have charge of the workshop. It is important for him to have a good knowledge of working in wood, and to be able in addition to do light metal-work. A knowledge of glass working should be acquired by practice.

2. *Constructive Work.*—We have described in this volume how certain pieces of apparatus may be made by the student. The knowledge of the use of tools and the properties of materials so gained is of great value. It cannot, however, be expected that any portion of the limited school time devoted to practical physics should be employed in constructive work. The students should rather be encouraged to make use of the workshop in their own time for this purpose. At residential schools this need not present much difficulty of arrangement.

3. *The Collective and Separate Systems.*—In the collective system all the students work at the same lesson at the same time. This enables the teacher to give collective instruction, and has other advantages from a didactic point of view. But one objection to the system is that it involves the multiplication of pieces of apparatus of the same kind, and hence without great expense it is impossible to have anything but the cheapest and simplest apparatus. It might be applicable to the earlier lessons on electrostatics, but could not be much used afterwards. It is a good method to commence with, but the *separate* system will soon be found necessary. In other words, all will not be working at the same lesson. It will not be found difficult to arrange the order of the lessons in such a way that no confusion shall result.

4. *The Indicator Board.*—The use of the separate system will be facilitated by adopting a device employed by Pickering, and since used at Cambridge and elsewhere. This consists of a board to show what work each student is doing. It may be made in various forms. "A convenient plan is to drive pins obliquely into a drawing-board in rows, so that they shall be separated about 3 inches horizontally and 2 inches vertically. The heads of the pins are then cut off and cards hung on them, those in the first vertical row bearing the names of the experiments, those in the other rows giving the names of the students."

5. *Companionships.*—It will be found advisable, as a rule, for students to work in couples. If a little discretion be exercised in selecting the companions, far more satisfactory work will be done than if they worked separately.

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